ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA-AZ96-433

A COMPARISON OF TRAFFIC NOISE FROM ASPHALT RUBBER ASPHALT CONCRETE FRICTION COURSES (ARACFC) AND PORTLAND CEMENT CONCRETE PAVEMENTS (PCCP)

Final Report

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February 1996

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-AZ-96-433		

4. Title and Subtitle	5. Report Date
A COMPARISON OF TRAFFIC NOISE FROM ASPHALT RUBBER ASPHALT CONCRETE FRICTION COURSES (ARACFC) AND PORTLAND CEMENT CONCRETE PAVEMENTS (PCCP)	February 1996
	6. Performing Organization Code
7. Authors	8. Performing Organization Report No.
Michael P. Henderson and Sylvester A. Kalevela	
9. Performing Organization Name and Address	10. Work Unit No.
JHK & Associates **Suite 3000** **121 Tijeras Avenue, NE** **Albuquerque, NM 87102**	11. Contract or Grant No. SPR-PL-1(47)433
12. Sponsoring Agency Name and Address	13.Type of Report & Period Covered
ARIZONA DEPARTMENT OF TRANSPORTATION **206 S. 17TH AVENUE** **PHOENIX, ARIZONA 85007**	Final Report: February 1995 to June 1995
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

A study was conducted by the Arizona Department of Transportation to evaluate the potential noise reduction benefits of using Asphalt Rubber Asphalt Concrete Friction Course (ARACFC) as an overlay for Portland Cement Concrete Pavements (PCCP). Comparative noise measurements were performed on several ARACFC and PCCP freeway segments. Third-octave frequency measurements were also performed to compare the frequency content of the noise generated by the two pavement types.

Two separate measurement techniques were used to collect noise data. First, roadside traffic noise measurements were performed on adjoining freeway segments that consisted of different pavement types. For these measurements, two noise meters were positioned at equal distances from the adjoining freeway segments, and roadside traffic noise levels were measured simultaneously. The second measurement technique consisted of on-road tire-pavement noise measurements. For these measurements, a specially made bracket was clamped to the frame of a test vehicle, and a noise meter microphone was secured near the tire-pavement contact area. Noise readings were recorded as the test vehicle traveled at highway speeds over various pavement surfaces. Noise frequency data was collected using both measurement techniques.

The noise data collected for the study demonstrated that the ARACFC freeway segments produced lower noise levels than the PCCP freeway segments. The extent of the noise differences observed between the two surface types depended on the specific freeway segments being compared. In some cases, the noise level differences would be distinguishable by human perception (differences of 3 decibels or greater). In other cases, the differences would not be noticeable. The frequency data collected for the study also indicated that the ARACFC surfaces generated less high frequency noise than the PCCP surfaces.

17. Key Words	18. Distribution Statement	23. Registrant's Seal
Noise, Traffic Noise, Pavement Noise, Tire-pavement Noise, Asphalt Rubber, Noise Measurement, Portland Cement Concrete	Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia, 22161	Registered Professional Engineer (Civil) CERTIFICATE NO. 9160 MICHAEL CONNORS Date Signed 1/3/96 ARIZONA, U.S.A.

19. Security Classification	20. Security Classification	21. No. of Pages	22. Price
Unclassified	Unclassified	166	

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
ml	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
ft oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

TEMPERATURE (exact)

Symbol	When You Know	Do The Following	To Find	Symbol
°F	Fahrenheit temperature	°F - 32 ÷ 1.8	Celcius temperature	°C

°C	-40	-20	0	20	37	60	80	100
°F	-40	0	32	80	98.6	160		212
			water freezes		body temperature			water boils

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.19	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.31	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T

TEMPERATURE (exact)

Symbol	When You Know	Do The Following	To Find	Symbol
°C	Celcius temperature	°C x 1.8 + 32	Fahrenheit temperature	°F

METER: a little longer than a yard (about 1.1 yards)
LITER: a little larger than a quart (about 1.06 quarts)
GRAM: a little more than the weight of a paper clip
MILLIMETER: diameter of a paper clip wire
KILOMETER: somewhat further than 1/2 mile (about 0.6 mile)

*SI is the symbol for the International System of Measurement

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1.0 INTRODUCTION

The Arizona Department of Transportation (ADOT) has been using asphalt-rubber materials in a variety of pavement treatments for over 25 years. One common application of asphalt-rubber has been in Asphalt Rubber Asphalt Concrete Friction Courses (ARACFC). In pavement treatments such as ARACFC, a crumb rubber modifier is added as a binder to the asphalt-concrete mixture. The use of scrap rubber in the pavement mixture provides a means for disposing of waste tires. In recent years, asphalt rubber pavements have also been promoted for reducing traffic noise.

Most of the urban freeways in Phoenix and Tucson are constructed of Portland Cement Concrete Pavements (PCCP). Concrete pavements provide a very durable pavement design strategy, however recent concern has focused on the noise generated by vehicle tires on concrete pavement surfaces. It has been suggested that substantial noise reduction benefits (3 - 5 decibels) can be achieved by using ARACFC as an overlay for PCCP.

Measures used to control traffic noise generally use one of two approaches: 1) reducing noise at its source, or 2) by limiting the propagation of noise energy between the source and noise-sensitive locations. The objective of this study was to evaluate the potential use of ARACFC as a means of reducing highway traffic noise at one of its primary sources, the tire-pavement interaction. To evaluate the effectiveness of using ARACFC as a strategy for reducing highway traffic noise, a comparison was made of the noise levels produced by ARACFC and PCCP roadway surfaces. As outlined below, the following chapters of this report document the research approach and findings of the study:

- **Chapter 2** Summarizes the findings of a literature review.
- **Chapter 3** Describes the study design effort.
- **Chapter 4** Presents the results of roadside traffic noise measurements.
- **Chapter 5** Presents the results of on-road tire-pavement noise measurements.
- **Chapter 6** Presents the results of frequency spectra measurements.
- **Chapter 7** Provides conclusions and recommendations of the study.

The following section provides background information on highway traffic noise, and a definition of several terms related to traffic noise issues.

1.1 Highway Traffic Noise - Background

Highway traffic noise is a complex phenomenon involving a variety of factors. The level of noise generated from traffic varies according to the volume of traffic on the roadway, vehicle travel speeds, and the vehicle mix of traffic, i.e., the number of cars and trucks in the vehicle stream. Noise is generated from individual vehicles by a combination of sources, including the vehicle engine and exhaust systems, wind turbulence, and the tire-pavement interaction. For passenger cars and light trucks, tire-pavement noise is the dominant noise source at highway travel speeds. For heavy commercial vehicles, the noise from engine and exhaust systems is also significant at higher speeds. Several factors affect the propagation of traffic noise to the roadside environment, including the distance of the noise receivers from the roadway, roadside topography, ground cover near the roadway, screening from barriers, reflections from buildings and other surfaces, and atmospheric conditions.

The human response that interprets the loudness of sound is directly related to the amplitude of pressure fluctuations, or acoustic vibrations, in the air. Sound pressure is described in units of the micropascal (μ Pa). The range of pressure fluctuations, or degrees of loudness, that the human ear can distinguish is extensive, ranging from 20 to over 6,000,000 μ Pa. The decibel, abbreviated dB, is a mathematical expression that reduces this wide range of audible sound pressures into a condensed, logarithmic scale. The decibel is defined as follows:

$$\textbf{Decibels} = \mathbf{20\ log_{10}(p/p_o)},$$
$$\textit{where } p = \textit{sound pressure (in } \mu \textit{ Pa)}$$
$$\textit{and } p_o = 20\ \mu \textit{ Pa (the threshold of hearing)}$$

When sound pressures are converted to decibels they are referred to as sound pressure *levels*, which are values on a scale relative to the selected reference sound pressure. When expressed in terms of decibels, noise levels correspond closely to the human auditory response to loudness. Because of the logarithmic nature of the decibel, and the similar human response to loudness, a change of 5 decibels, for example, would produce the same perceived change in loudness at any noise level. In general, human hearing can begin to distinguish a difference in loudness when noise levels change by 3 decibels. A noise level increase of 5 decibels would be regarded as being slightly louder. An increase of 10 decibels would be perceived as a doubling of loudness.

The pitch or frequency of a noise is described in units of Hertz (Hz). The frequency range of normal human hearing is between 20 and 20,000 Hz. However, human hearing is not equally sensitive to all sound frequencies. Noises with extremely low frequencies (less than 500 Hz) or extremely high frequencies (over 10,000 Hz) are attenuated by the human hearing mechanism. For most transportation noise evaluations, an A-weighting filter is used to correlate physical noise levels with the frequency sensitivity of human hearing and the subjective response to noise. Noise levels reported in A-weighted decibels are commonly abbreviated dBA.

Traffic noise is comprised of a wide range of frequency components and is often referred to as a broad-band noise. To describe the frequency distribution for a given noise, individual noise frequencies are grouped into octave bands, which divide the sound spectrum into specific frequency ranges. Each octave band is referred to by its center frequency (the geometric mean of its frequency range). More detailed information on the frequency content of a noise can be obtained by further dividing each octave band into three smaller parts. These smaller units are called third-octave bands.

2.0 LITERATURE REVIEW

The initial task of the study was to conduct a literature review of past research efforts aimed at evaluating tire-pavement noise. The review focused on determining the most suitable methods for measuring and evaluating noise levels produced by different pavement surfaces. The following sections highlight the findings of the literature review. Included is a brief discussion concerning the mechanisms of tire-pavement noise and a summary of the most common methods used for data collection and data analysis found in the literature.

2.1 Mechanisms of Tire-Pavement Noise

Noise generated from individual vehicles is attributed to several sources including engine noise, exhaust noise, wind turbulence, and the tire-pavement interaction. According to the literature, researchers are in general agreement that tire-pavement noise is generally considered the primary source of traffic noise when travel speeds are 45 miles per hour or greater[1,2,3,4,5]. Therefore, it is appropriate to consider noise-reducing pavements as a means of mitigating traffic noise, especially for highway traffic situations. However, it should be noted that tire-pavement noise is only one of the many factors that influence overall traffic noise levels.

The literature describes roadway-tire noise itself as a complex phenomenon consisting of multiple mechanisms. Several of the mechanisms described in the literature[5,6,7,8] are provided below:

- A slap down effect occurs at the leading edge of the tire as the treads meet the roadway. Air is forced out from between the tread elements and the roadway (this effect is referred to as "air pumping").

- Tire vibrations, caused by irregularities in the pavement surface, occur in the tire-pavement contact patch. Some of the tire's kinetic energy is converted into acoustic energy.

- Noise is generated at the trailing edge of the tire as the tread is released from the road surface. Pressurized air trapped between the tread and the pavement surface is released ("air pumping"). As the tread snaps back, a resonance effect is produced within the tire tread.

It has been reported that different mechanisms may be responsible for noise generation within certain frequency bands. In addition, different tire types and tread patterns from individual vehicles have been shown to affect these mechanisms in a variety of ways[1]. Furthermore, numerous studies have reported important differences in the frequency content and noise levels produced from different pavement surfaces[4,9,10,11].

In past research efforts concrete pavements have generally been shown to produce more noise than bituminous roadway surfaces. More specifically, open graded asphalt surfaces have been shown to produce lower noise levels than tined or deeply grooved concrete surfaces[12,13]. Differences of nearly 10 decibels in roadside noise levels have been reported between these two surface types[14]. The differences in noise produced by these surfaces are generally attributed to the differences in surface texture, rather than the concrete and bituminous materials themselves. In general, higher noise levels are produced by rough roadway surfaces[3,5,15].

Open graded asphalt surfaces and other so called "quiet pavements" or surface treatments are reported to affect the tire-pavement noise generating mechanisms by employing a porous surface with a high void content[2,11,12]. It is theorized that "quiet" surfaces generate less noise than PCCP surfaces because of these surface voids, which allow air to escape more readily from the tread-pavement contact area and thus reduce the "air pumping" effect. Some researchers have determined that certain roadway surfaces also provide noise attenuation by absorbing some of the tire-pavement noise that would otherwise be transmitted to roadside locations[2,11].

Some evaluations have been conducted to compare the noise reduction benefits for pavement surfaces constructed with asphalt-rubber materials, such as ARACFC[16]. These studies, performed in various countries, have shown that noise reduction benefits of 2 - 10 decibels can be achieved by using a combination of asphalt rubber pavement mixtures on pavements with open-graded surface textures.

2.2 Data Collection Methods

The literature provides several examples of data collection methods that have been used to evaluate tire-pavement noise[6,17,18,19]. Four principle data collection methods have been used. Some of the measurement methods have been developed to meet vehicle manufacturer and tire industry specifications and/or the vehicle noise regulations of certain countries. The four principal measurement methods identified in the literature review are provided below.

- The laboratory drum method. A test tire is mounted to roll against a drum surface in a laboratory. The microphone is positioned near the tire-drum interface. Different drum surfaces or tires can be tested to evaluate their relative noise effects.

- Roadside noise measurements of individual vehicle passbys. A vehicle coasts by a roadside microphone with the engine switched off. Different vehicles/or tires can be coasted over a standardized pavement surface to evaluate their rolling noise levels or to determine if a vehicle meets a given noise specification.

- Roadside traffic noise measurements. Traffic noise measurements are made adjacent to different pavement surfaces for comparison. This method measures the overall changes in traffic noise that can be attributed to a given pavement surface. Noise measurements can be made before and after a new pavement surface is applied at a given location, or simultaneous measurements can be conducted on adjoining roadway segments with different pavement types.

- On-road tire-pavement method. A microphone is mounted on a trailer or boom close to the tire-pavement contact area. The test tire is driven over various pavement surfaces or with different tires to determine their relative noise effects.

2.3 Data Analysis

Data analysis methods were found to be very similar among the various studies reviewed in the literature[11,12,14,20]. Data analysis focuses on comparing the noise levels produced by the various pavement surfaces. This data is normally expressed in terms of an average (or equivalent) noise level over a unit of time, in A-weighted decibels, abbreviated Leq dBA. A wide range of averaging times has been used, from several minutes to an hour or more. According to the literature, the arithmetic mean of several Leq measurements provides a reasonable means of quantifying the noise generation characteristics of an individual pavement, if similar conditions are present for each measurement.

While FHWA's traffic noise abatement criteria rely solely on the Leq dBA measurement, several investigators have considered the spectral content to be an important issue in pavement noise studies. Perceptible noises range in frequency from approximately 20 to 20,000 Hertz (Hz). Sounds of 2,000 Hz and above are generally regarded as the most annoying and disruptive, especially if discrete frequency components are present[21]. It was emphasized in the literature that subjective reports often favor certain pavement types as producing less noise than others, even though the overall difference in Leq values should not have been perceivable. The literature explains this subjective response as a reduction in noise generated in the higher frequency bands, which are normally more annoying to people than lower frequencies[11,14]. Frequency information was collected as part of this study to consider these potential subjective responses to the noise generated by different pavement surfaces.

3.0 STUDY DESIGN

3.1 Measurement Methods

Of the four measurement methods described in the literature review, two were selected to evaluate the noise generation characteristics of ARACFC and PCCP roadway surfaces: 1) roadside traffic noise measurements, and 2) on-road tire-pavement noise measurements. The two separate approaches were selected based on the different advantages offered by each technique.

Both the roadside and on-road measurement techniques offer specific advantages and disadvantages. For example, roadside traffic noise measurements can be used to measure "real world" noise levels produced from different pavement surfaces. Noise measurements conducted using this technique reflect the complex array of variables that influence highway traffic noise, including pavement surface type. However, when simultaneous noise measurements are performed on two different pavements, it is necessary to select measurement sites where traffic volumes, travel speed, vehicle mix, and site acoustics are similar. Thus, the number of potential measurement sites is limited. Furthermore, measurements conducted using this method are necessarily restricted to evaluating the noise produced by relatively short sections of freeway, near the location where the measurements are being performed.

Conversely, the on-road measurements can be performed on any pavement surface, and large amounts of data can be collected over long stretches of a freeway surface. With the on-road measurement method, several potential measurement problems can be eliminated. For example, it is not necessary to account for variations in traffic flow or roadside acoustics. The on-road measurement technique also provides a means for isolating the noise generated from the tire-pavement interaction. There are disadvantages to this measurement method as well. Although this technique can be used to compare the relative tire-pavement noise levels from different pavements, little can be said about noise levels experienced at the roadside based on this measurement approach.

The simultaneous roadside traffic noise and on-road tire-pavement noise measurement methods offer two separate approaches for evaluating the noise generation characteristics of different roadway surfaces. Because of the specific advantages and disadvantages of the two measurement techniques, both approaches were used in this study as independent methods of evaluating tire-pavement noise. No attempt was made to correlate on-road tire-pavement noise levels with roadside traffic noise levels, other than to note general consistencies in the results of the two measurement approaches. Specific advantages and disadvantages of the two methods are summarized in Table 3-1.

TABLE 3-1
ADVANTAGES AND DISADVANTAGES OF NOISE MEASUREMENT METHODS

Data Collection Issue	Method Advantages/Disadvantages	
	Roadside Traffic Method	**On-Road Tire-Pavement Method**
Site selection	Limited by number of suitable locations, i.e., locations having identical traffic characteristics and acoustical environments.	Can be used on any pavement surface. A large amount of data can be collected quickly.
Ease of measurement technique	Generally, equipment setup is easily accomplished. Prior testing is not necessary for data collection.	Requires design and construction of a special trailer, mounting or boom. Testing is necessary to ensure method precision.
Potential measurement problems	Traffic composition, volume, and speed must remain constant at two measurement sites for a direct comparison of noise levels to be meaningful.	Artificial noise effects such as wind noise, adjacent traffic noise, etc., would have to be minimized. Not limited by traffic fluctuations or roadside acoustics.
Realistic versus relative noise levels	Good at showing realistic noise effects that different pavement surfaces produce on the roadside environment. Relates these differences based on a realistic mixture of traffic noise sources.	Good at showing a relative difference in how the noise generated from an individual tire changes across various pavement surfaces. Not a "real world" noise phenomenon.
Meteorological variance	Could substantially affect roadside measurements if conducted at different times of day or under different conditions.	Little or no effect.
Travel speeds	Measurements could only be performed for the average travel speed occurring in traffic during the measurement period.	Could test pavement-tire noise relationship at different speeds.
Frequency analysis	Is possible.	Is possible.

3.2 Site Selection

At the initiation of the study, an inventory of locations was prepared that identified all locations where ADOT has used ARACFC pavement treatments on Arizona freeways. ARACFC has been applied on segments of I-19 near Tucson, and on segments of I-10 and I-17 near Phoenix. Noise measurement were conducted for each of these locations. Noise measurements were also conducted for an additional freeway location consisting entirely of PCCP (I-10, in Tucson). The freeway locations considered in the noise study, and the type of noise data collected for each location, are shown in Table 3-2. These locations are shown graphically in Figure 3-1.

For this study, freeway l*ocations* refer to the general area of a particular freeway included in the evaluation. Each one of the identified freeway locations consists of multiple freeway *segments*. Freeway *segments* refer to a specific length of freeway that is constructed with a single surface type, such as ARACFC.

A variety of surface treatments can occur on PCCP roadways. Since pavement surface texture is thought to be an important factor in the generation of tire-pavement noise, the surface treatments of the various PCCP roadways evaluated in the study were noted. When ADOT constructs a new PCCP freeway section, the pavement surface is normally tined before the concrete mixture dries. *Tining* involves dragging a rake-like instrument with fine tines across the drying concrete surface. The tining produces shallow ridges in the pavement that improve the friction of the roadway surface. Tining is performed in the transverse direction of the roadway, that is, in the direction perpendicular to the roadway centerline. As PCCP surfaces age, different rehabilitation operations are performed to improve their skid resistance and ride. These rehabilitation procedures can substantially alter the surface texture of the pavement. *Grooving* is sometimes performed on aging pavements to improve skid resistance (normally after approximately 10 years of service life). For this procedure, a series of saw blades are used to cut grooves into the pavement that are approximately 3/16 of an inch in depth and spaced approximately 3/4 of an inch apart across the pavement surface. Grooving is nearly always performed in the longitudinal direction, that is, in the direction parallel to the roadway centerline. *Grinding* is a more common rehabilitation procedure that is used

TABLE 3-2
FREEWAY LOCATIONS INCLUDED IN PAVEMENT NOISE EVALUATION

Location Number	Freeway/General Area	Mile Post	Noise Data Collected: Roadside	Noise Data Collected: On-road
Location 1	I-10 (50 miles west of Phoenix)	94.7 - 112.2	x	x
Location 2	I-17 Phoenix	194.5 - 226.0		x
Location 3	I-10 Tucson	254.5 - 260.4	x	x
Location 4	I-19 Tucson	87.7 - 100.7	x	x

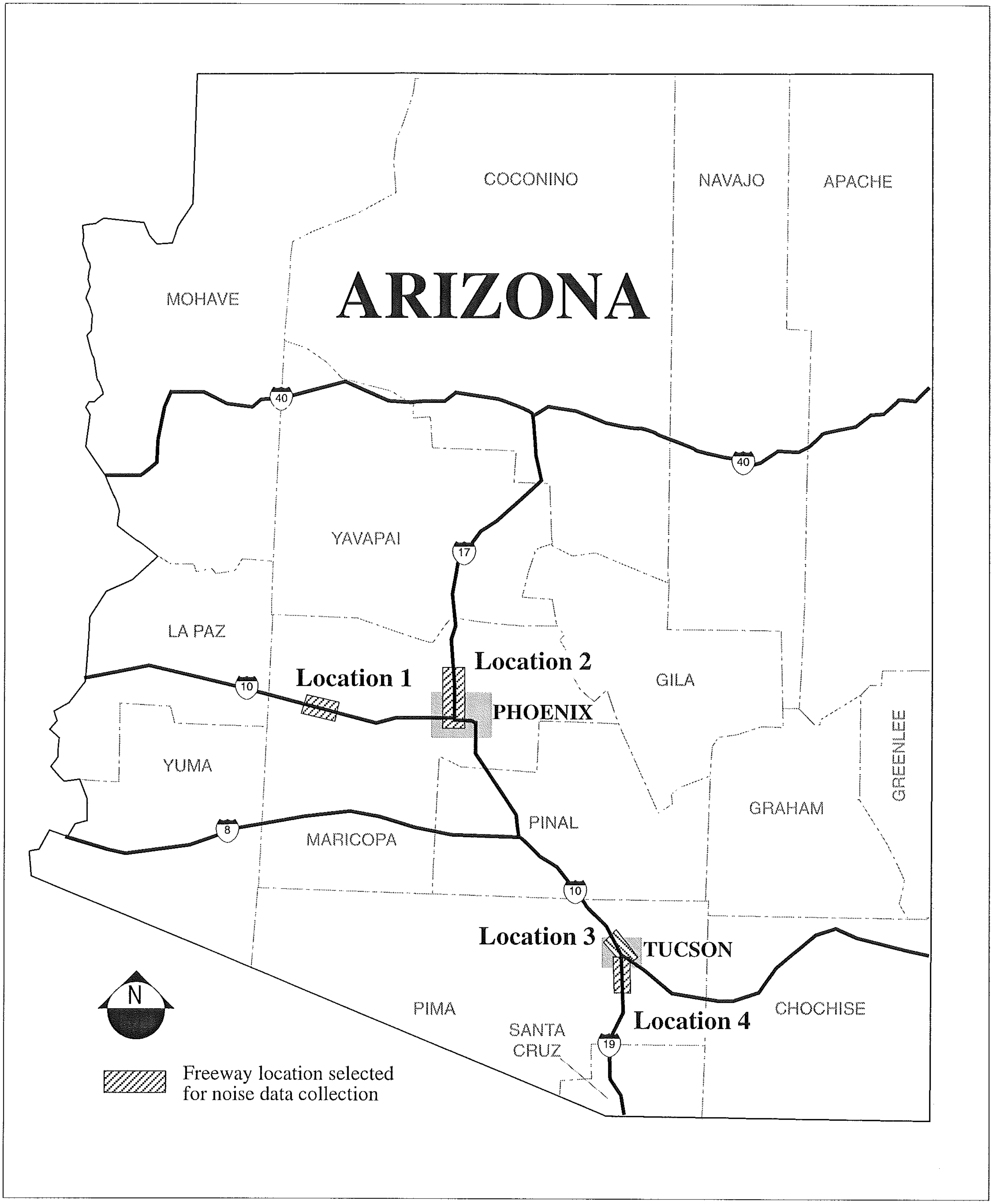


FIGURE 3-1
LOCATION MAP

to improve both the skid resistance and the ride of aging PCCP roadways. The grinding procedure involves using a bank of saw blades to grind away a thin layer from the entire pavement surface. Grinding smoothes out deformities that have developed in the pavement surface profile and improves the frictional characteristics of the surface. Grinding can also be performed on surfaces that have been previously grooved. Like grooving, grinding is normally performed in the longitudinal direction.

Table 3-3 summarizes the different surface types found at each freeway location and segment, and the approximate mile post separating each surface type. Freeway Locations 1, 2 and 4 consist of separate ARACFC and PCCP segments. These locations were used to conduct comparative noise measurements. Noise measurements were also conducted for Location 3 (I-10 in Tucson), however the roadside noise data collected for this location was not used for comparative purposes as part of this study. Location 3 consists of two separate PCCP segments. According to ADOT, ARACFC will be used as an overlay on one of these PCCP segments sometime in 1995. The roadside noise measurements conducted at this location can be used as a comparison with future noise levels after the ARACFC surface is applied. For future use, the data collected at Location 3 is provided in Appendix A.

TABLE 3-3
ROADWAY SURFACES PRESENT AT EACH FREEWAY LOCATION

Location	Segment Mile Post	Segment Surface Type	Segment Construction Year
Location 1	94.72 - 105.95	ARACFC	1994
I-10 West of Phoenix	105.95 - 108.95	PCCP, tined	1994
	108.95 - 112.2	ARACFC	1994
	194.5 - 198.78	ARACFC	1992
Location 2	198.78 - 199.9	PCCP, ground	1991
I-17 Phoenix	210.98 - 213.44	PCCP, ground	1988
	214.7 - 226.0	ARACFC	1994
Location 3	254.5 - 260.4 *	PCCP, ground	1983
I-10 Tucson	261.4 - 267.5	PCCP, ground	1989
Location 4	54.8 - 58.48	PCCP, grooved	1988
I-19 Tucson	58.48 - 60.2	ARACFC	1988
	60.2 - 62.95	ARACFC	1992

* *This segment will be overlaid with 1" ARACFC in 1995. Noise measurements were conducted for this segment for comparison with future measurements after the new ARACFC surface is present.*

3.3 Roadside Traffic Noise Measurements

For the roadside traffic noise measurements, two noise meters were positioned adjacent to adjoining pavement segments with different surface types, and noise levels were recorded simultaneously at each site. The noise levels measured at the two sites were then compared to give a relative measure of the noise generation characteristics of the two surfaces.

The intent of conducting simultaneous noise measurements was to minimize variability in the noise measurements due to changes in traffic flow and local meteorology that would potentially occur if the two measurements were to be performed at different times. An effort was also made to select measurement sites with similar acoustic surroundings. The following characteristics were used to evaluate the similarity between each pair of sites used for the simultaneous traffic noise measurements:

- Similar traffic flow characteristics at both sites, including vehicle volumes, truck percentages, and average speeds. Where possible, locations were selected where a transition between ARACFC and PCCP roadway surfaces occurred between service interchange locations.

- Minimal freeway grade at both measurement sites.

- Similar sound propagation rate due to ground attenuation at both sites, i.e., a "hard" or "soft" site, according FHWA traffic noise modeling procedures.

- Absence of nearby reflective surfaces at both sites, such as adjacent buildings, privacy walls, etc.

- Similar roadside topography. Generally, locations where the roadside surroundings were flat and vacant.

- Locations with minimal background noise sources, such as neighborhood noises and traffic noise from nearby roadways.

To ensure that potential differences between the noise monitoring equipment was also considered, each noise meter was calibrated at least twice each day that measurements were performed. Before conducting the roadside measurements, both noise meters were positioned at the same site, and noise measurements were conducted for intervals of 10 to 15 minutes. The noise levels measured by both meters were recorded to determine if any of noise level differences observed in the simultaneous roadside noise measurements could be attributed to the instruments. The calibration data for each roadside measurement is presented with the complete noise monitoring data in Appendix A.

Traffic data was collected while each of the roadside traffic noise measurements was being conducted. This information was used to verify that traffic conditions were similar at both measurement sites. Traffic data consisted of vehicle volume, vehicle classification, and travel speed for each measurement site. The traffic data collected at each site is provided in Appendix A.

Based on the location characteristics identified for the roadside traffic noise evaluation, segments of Location 1 (I-10, approximately 50 miles west of Phoenix) and segments of Location 4 (I-19, south of Tucson) were selected for conducting the simultaneous roadside noise measurements. No suitable roadside measurements sites were found for Location 2 (I-17, in Phoenix) due to varying traffic flow conditions on the adjoining PCCP-ARACFC segments, and due to substantial differences observed in the roadside terrain surrounding these freeway segments.

3.4 On-Road Tire-Pavement Noise Measurements

For the on-road noise measurements, a specially made bracket was clamped to the frame of a test vehicle, a 1995 Dodge Caravan. A noise meter microphone/preamplifier was secured to the bracket near one of the rear tires of the test vehicle. The microphone was secured 10 inches from the tire-pavement contact area for all of the on-road measurements. A specially made windscreen was also clamped in front of the microphone bracket to minimize the effects of wind noise. Photographs of the test vehicle, showing the microphone bracket and windscreen are provided in Figure 3-2

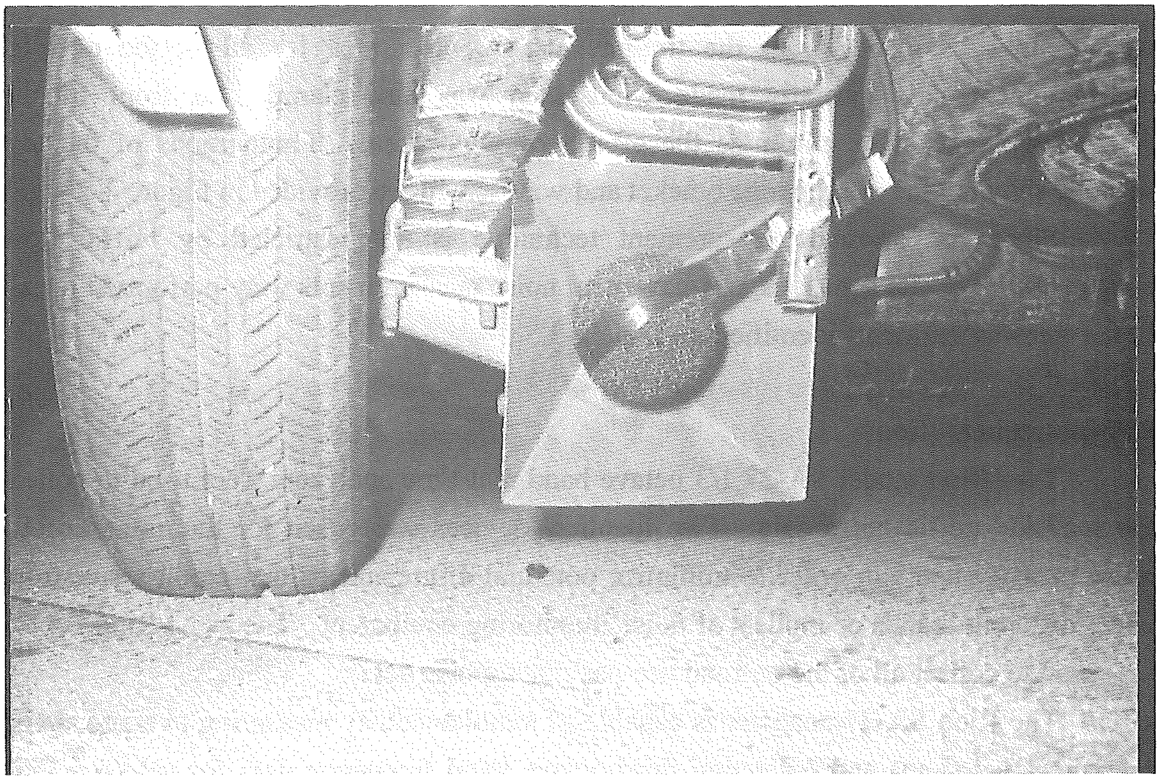
Since the on-road measurement technique is not restricted by traffic flow characteristics or site acoustics, tire-pavement noise measurements were performed for all of the freeway segments identified in Table 3-3.

3.5 Instrumentation

Two Rion model SA-27 1/3 octave band real-time analyzers were used to collect the roadside traffic noise data. Two identical devices were used for the simultaneous noise measurements in order to minimize potential discrepancies that could result from using different brands or models of noise monitoring equipment. The same Rion SA-27 was used to collect all of the on-road tire-pavement noise data.

The Rion SA-27 analyzer is capable of simultaneously measuring average sound pressure level (Leq) and collecting third-octave band frequency data for selected time intervals. The SA-27 meets ANSI S1.11 and IEC 225 standards for third-octave band

Test Vehicle - 1995 Dodge Caravan



Microphone Bracket and Windscreen

JHK & Associates
An SAIC Company

FIGURE 3-2
TEST VEHICLE AND MICROPHONE ATTACHMENTS

analyzers. Average 1/3 octave values are recorded both numerically and graphically by the SA-27, and a built-in printer can be used for providing an immediate hard copy of the measurement results. A Larson-Davis CA 250 precision calibrator (114.0 dB, 250 Hz) was used to calibrate both analyzers before each roadside measurement period, and prior to conducting the on-road measurements.

4.0 ROADSIDE NOISE MEASUREMENTS

Roadside traffic noise measurements consisted of simultaneously measuring traffic noise levels on two adjacent freeway segments with different surface types. Two noise meters were positioned an equal distance from the travel lanes of the adjoining freeway segments, and simultaneous noise measurements were conducted for a one hour period. The hourly equivalent noise levels (Leq) measured for the two sites were then compared to determine the relative noise generation characteristics of the two freeway surfaces being tested.

The simultaneous noise measurements were performed at a distance of 25 feet from the nearest freeway travel lane, and also at the edge of freeway right-of-way (60-100 feet from the nearest travel lane, depending on the right-of-way width at a given measurement site). Eight pairs of simultaneous measurements were performed to provide information on the relative noise produced by ARACFC and PCCP surfaces (four at Location 1, and four at Location 4). Four pairs of simultaneous measurements were performed to compare the noise levels produced by two ARACFC segments of different ages (all at Location 4).

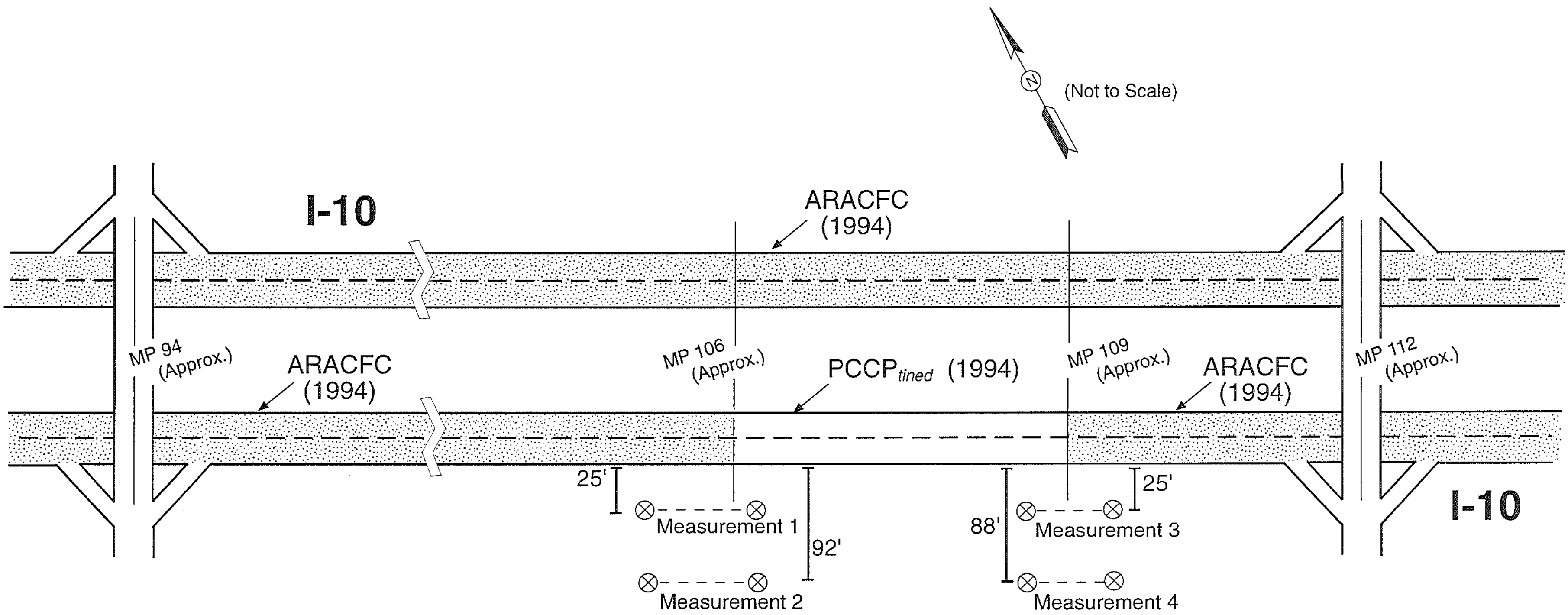
The following paragraphs summarize the results of the roadside traffic noise measurements at the two selected freeway locations: Location 1 (I-10, west of Phoenix) and Location 4 (I-19, Tucson).

4.1 Location 1: I-10 M.P. 94-112 (West of Phoenix)

Figure 4-1 shows a schematic of the pavement transitions and noise monitoring locations selected for Location 1 on I-10. Location 1 consists of an eighteen-mile stretch of I-10, located approximately 50 miles west of Phoenix. As shown in Figure 4-1, the eastbound direction of I-10 consists of adjoining ARACFC and transversely tined PCCP surfaces. The westbound freeway surface consists of ARACFC for its entire length. All ARACFC and PCCP freeway segments at Location 1 were constructed in 1994.

As shown in Figure 4-1, the tined PCCP segment is situated between two ARACFC segments. One highly desirable aspect of this location is that all three pavement sections are located between the same two freeway interchange locations. This ensured that hourly traffic volumes, travel speeds, and truck percentages, would essentially be the same at each pair of noise measurement sites.

Roadside acoustic properties were also similar at each pair of measurement sites. The entire length of I-10 considered in Location 1 is located in a rural setting, with only vacant lands adjacent to the selected monitoring sites. The vegetation surrounding the freeway is generally consistent throughout the area, consisting of desert grasses and scrub



Noise Monitoring Summary
(Location 1: March 13, 1995)

Simultaneous Measurements	Time	Leq dBA (1 hour) ARACFC	Leq dBA (1 hour) $PCCP_{tined}$	Difference
Measurement 1	1:30 - 2:30 PM	71.8	77.5	5.7
Measurement 2	2:45 - 3:45 PM	63.9	68.5	4.6
Measurement 3	5:20 - 6:20 PM	72.9	78.2	5.3
Measurement 4	6:35 - 7:35 PM	66.5	69.8	3.3
			Average	4.7

LEGEND

⊗ Noise Monitoring Site

⊗- - -⊗ Simultaneous Noise Measurement

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FIGURE 4-1
SCHEMATIC FOR LOCATION 1
I-10 WEST OF PHOENIX

brush. Some slight variation occurs in the surrounding topography at different locations near the freeway. However, each pair of measurement sites were selected where the noise meter microphones could be positioned at the same height above the roadway.

Simultaneous roadside traffic noise measurements were performed in the afternoon and evening of March 13, 1995. A summary of the hourly noise data collected for each measurement is provided on Figure 4-1. The traffic and noise data collected at each site is provided in its entirety in Appendix A.

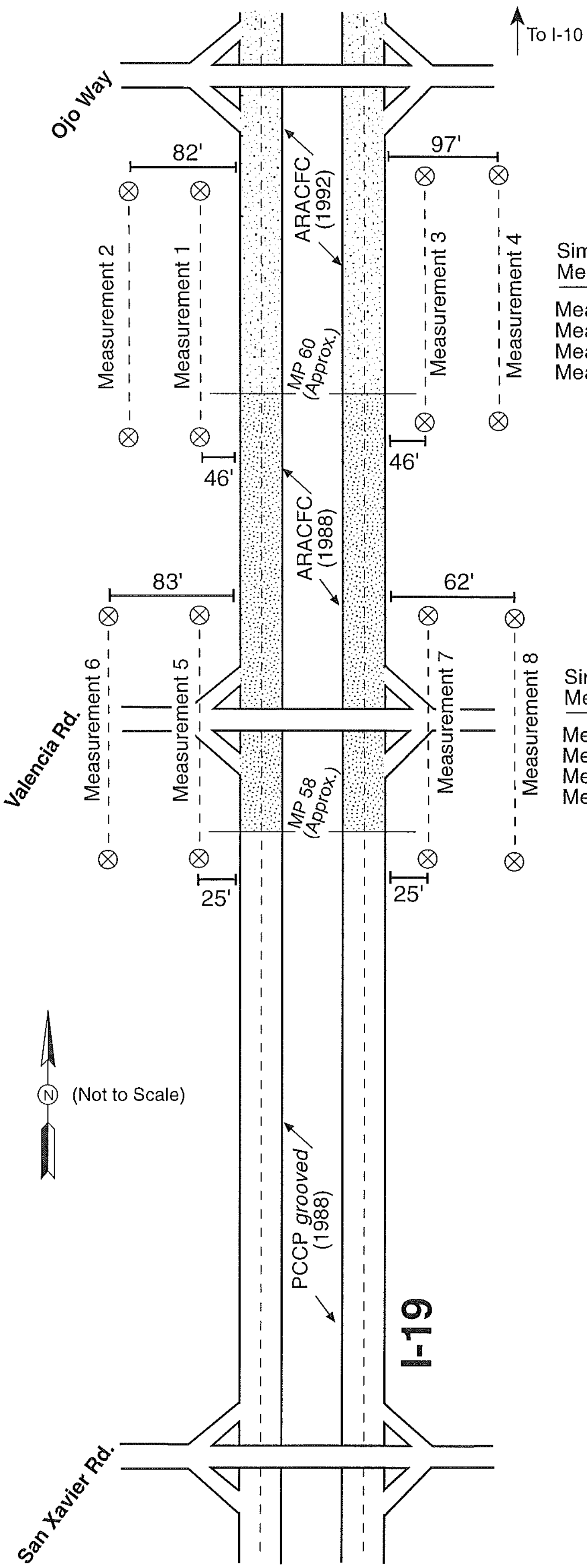
As shown on Figure 4-1, roadside traffic noise levels were consistently higher at the monitoring sites adjacent to the tined PCCP surface than the ARACFC surfaces. The difference in hourly noise levels measured for the two pavement surfaces ranged from 3.3 dBA to 5.7 dBA. Since each pair of measurement sites was selected to maintain equivalent traffic flow, travel speeds, and site acoustics during the measurements, it is reasonable to conclude that the differences in measured noise levels were due to the different pavement surfaces being evaluated.

Based on the roadside noise data collected at Location 1, roadside traffic noise adjacent to the ARACFC surface would be perceived as slightly less noisy than the PCCP surface. Although noise level differences of 3.3 - 5.7 dBA would only be perceived as slightly less noisy than the adjoining PCCP surface, it is useful to consider these differences in terms of sound pressure. At any noise level, a three decibel difference corresponds to a halving (or doubling) of sound pressure. Accordingly, a change of three decibels would be expected if the traffic volumes were to change by a factor of two (doubling traffic would increase noise levels by three decibels, and halving traffic would reduce noise levels by three decibels, if all other factors remained constant). In all of the noise measurements performed at Location 1, the ARACFC segments provided more noise reduction than would have been achieved by reducing traffic on the PCCP freeway segment by 50%. The greatest difference in noise produced by the two pavements, 5.7 dBA, would be equivalent to a traffic reduction of nearly 75% on the PCCP segment.

4.2 Location 4: I-19 M.P. 63-55 (Tucson)

Simultaneous roadside traffic noise measurements were also conducted on I-19 in Tucson. Location 4 consists of an eight mile long stretch of I-19, beginning at the I-10/I-19 interchange and extending south to the Papago Road interchange. A schematic of I-19 showing the noise monitor locations and pavement transition areas within Location 4 is provided in Figure 4-2.

As shown in Figure 4-2, three different pavement segments were evaluated for Location 4. Immediately south of the I-10/I-19 interchange, the I-19 roadway surface consists of an ARACFC overlay that was constructed in 1992. Approximately 1.5 miles



Noise Monitoring Summary
(Location 4: March 16, 1995)

Simultaneous Measurements	Time	Leq dBA (1 hour) ARACFC 1992	ARACFC 1988	Difference
Measurement 1	9:25 - 10:25 AM	70.3	70.9	0.6
Measurement 2	10:35 - 11:35 AM	67.4	68.5	1.1
Measurement 3	1:45 - 2:45 PM	71.8	72.8	1.0
Measurement 4	3:00 - 4:00 PM	66.8	68.3	1.5
			Average	1.0

Noise Monitoring Summary
(Location 4: March 17, 1995)

Simultaneous Measurements	Time	Leq dBA (1 hour) ARACFC 1988	$PCCP_{grooved}$	Difference
Measurement 5	8:15 - 9:00 AM	75.6	77.7*	2.1
Measurement 6	9:10 - 10:00 AM	68.7	70.0*	1.3
Measurement 7	11:05 - 11:50 AM	74.5	76.4*	1.9
Measurement 8	12:00 - 12:50 PM	70.6	70.8*	0.2
			Average	1.4

*Value adjusted to reflect equal traffic levels for this location using the Stamina model

LEGEND

⊗ Noise Monitoring Site

⊗- - -⊗ Simultaneous Noise Measurement

FIGURE 4-2
SCHEMATIC FOR LOCATION 4
I-19 NEAR TUCSON

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An SAIC Company

south of I-10, this segment transitions to an older ARACFC surface that was constructed in 1988. Approximately 1.5 miles farther south, just south of a service interchange, the 1988 ARACFC transitions to longitudinally grooved PCCP. The grooved PCCP segment extends for approximately four miles south of the interchange. The northern portion of the freeway configuration shown in Figure 4-2 was used to evaluate the traffic noise levels for the two ARACFC surfaces of different ages (these surfaces were constructed approximately four years apart). The southern portion of the freeway was used to evaluate the traffic noise levels of the grooved PCCP in comparison to the older of the two ARACFC surfaces.

The length of I-19 considered in Location 4 is located in suburban to rural settings south of Tucson. Along the northern half of Location 4, several residential neighborhoods are present on the east side of I-19. The west side of I-19 is predominantly vacant. Noise measurement sites were selected on both sides of the freeway. In some cases, the nearby neighborhoods may have contributed background noise to the monitoring data, especially at the measurement sites set back near the edge of right-of-way. Observations regarding neighborhood and other background noises were recorded during field noise monitoring. These observations are included in Appendix A.

Some variation occurs in the topography surrounding the freeway near Location 4. To minimize any effects that variations in topography might produce in the roadside measurements, each pair of monitoring sites was selected where the noise meter microphones could be positioned at the same height above the adjacent traffic lanes. Generally, the microphone positions ranged between 3-8 feet above the roadway.

Simultaneous roadside traffic noise data was collected near the adjoining freeway segments on March 16 and March 17, 1995. The March 16 measurements were conducted adjacent to the two ARACFC surfaces of different ages. These measurements were performed to evaluate how the noise levels produced by the ARACFC surface might change over time. The March 17 measurements were conducted adjacent to the grooved PCCP and 1988 ARACFC surfaces. Four simultaneous one-hour measurements were performed on both days. A summary of the hourly noise data collected for both days is provided on Figure 4-2. Results from the simultaneous roadside noise measurements are provided in the following sections.

4.2.1 Comparison of 1988 ARACFC with 1992 ARACFC

As shown in Figure 4-2, hourly average noise levels were slightly higher adjacent to the 1988 ARACFC than those measured adjacent to the 1992 ARACFC surface. Differences in the simultaneous noise measurements ranged from 0.6 - 1.5 dBA for the two surfaces. As noted previously, a difference of 3 dBA is normally required before a difference in noise levels is observed by human hearing. Therefore, the difference in noise levels produced by the two surfaces would not be perceivable. However, the roadside traffic noise measurements demonstrate that some differences exist in the noise generation characteristics of the two ARACFC surfaces.

Although the hourly Leq measurements were consistently higher adjacent to the older ARACFC surface, it not clear whether these subtle differences are a result of pavement aging. It is possible, for example, that the 1988 ARACFC surface produced these slightly higher noise levels when it was new. Without some measure of the noise produced by the 1988 ARACFC at an earlier phase of its service life, it is impossible to draw any conclusions about how its noise generation characteristics may have changed over time. The collected data can only demonstrate that the 1988 ARACFC surface currently produces slightly higher noise levels than the 1992 ARACFC surface, and that the differences in noise produced by the two surfaces are minor.

4.2.2 Comparison of 1988 ARACFC with grooved PCCP

Figure 4-2 also summarizes the hourly noise levels measured adjacent to the 1988 ARACFC in comparison to the grooved PCCP. As shown in Figure 4-2, the transition between these two pavements occurs near a service interchange. This condition resulted in traffic volume differences at the simultaneous noise monitoring sites. During the roadside traffic noise measurements, substantially higher traffic volumes were observed on the ARACFC segment than those found on the PCCP segment south of the interchange. To correct for this discrepancy, FHWA's traffic noise prediction model, STAMINA 2.0, was used to adjust the noise levels measured at the PCCP measurement sites.

To make this adjustment, the STAMINA model was first calibrated so that noise levels predicted by the model would be the same as field-measured noise levels. Roadway and receiver geometry for the PCCP measurement sites were input into STAMINA and modeling was performed using traffic data collected during noise monitoring. This data included traffic volumes, truck percentages and average travel speeds collected during each hourly measurement. Minor adjustments were then made to STAMINA input parameters so that modeled noise levels would be identical to the noise levels measured at the various PCCP monitoring sites. After the model was calibrated in this manner, the traffic parameters used in the model were changed to the values recorded at the adjacent ARACFC sites. Using this modeling process, the noise levels measured at the grooved PCCP monitoring sites were adjusted to reflect the same traffic conditions found on the adjacent ARACFC segment. A detailed description of this adjustment is provided in Appendix B of this report. The noise levels presented for the PCCP surface in Figure 4-2 reflect this adjustment.

As shown in Figure 4-2, noise levels for the PCCP segment were 0.2 - 2.1 dBA higher than the levels measured for the ARACFC segment. Similar to the differences observed between the two ARACFC pavements of different ages, these differences in noise are regarded as minor. However, the consistently higher hourly noise levels (after adjusting for traffic flow) indicate that some differences exist in the noise generation characteristics of the two surfaces.

Of interest is the fact that the noise level differences observed between the ARACFC and grooved PCCP at Location 4 were much less than the differences observed between the ARACFC and the tined PCCP surface found at Location 1 (on I-10, west of Phoenix). This finding indicates that differences may exist in the noise generation characteristics of the grooved PCCP and tined PCCP surfaces as well.

5.0 ON-ROAD TIRE-PAVEMENT NOISE MEASUREMENTS

For the on-road tire-pavement noise measurements, a Dodge minivan was equipped with a microphone that was secured on the exterior of the vehicle near the tire-pavement contact area. Tire-pavement noise levels were recorded as the van traveled over the various freeway segments considered in the study. For these measurements, 10-second Leq noise levels were collected as the test vehicle traversed each freeway segment. The Leq values were recorded for travel speeds of 55 and 65 miles per hour. More than 700 10-second Leq noise measurements were collected. Complete results of the on-road tire-pavement noise measurements are provided in Appendix C.

Since the on-road measurement technique was not restricted by differences in traffic volume or site acoustics, noise data for all of the freeway segments could be compared directly. The following sections summarize the analysis that was performed for the on-road tire-pavement noise measurements.

5.1 Comparison of ARACFC and PCCP Pavement Types

To compare the on-road tire-pavement noise levels produced by ARACFC and PCCP freeway segments, the 10-second Leq noise measurements were sorted and grouped according to the two general pavement types. To minimize any bias that could have resulted from including pavements of different ages, only noise measurements from freeway segments constructed between 1988 and 1994 were selected. Table 5-1 provides a summary of the average Leq values for the ARACFC and PCCP surface types, for test speeds of 55 and 65 miles per hour. Figure 5-1 and Figure 5-2 present this information graphically.

As shown in Table 5-1 and the accompanying figures, PCCP freeway segments produced higher average, minimum, and maximum noise levels than ARACFC segments. Average noise levels for PCCP surfaces were 3.0 - 3.1 dBA higher than ARACFC surfaces. A relatively wide range of values were recorded for both pavement types. The range of minimum to maximum noise levels measured for the ARACFC surfaces was 3.9 decibels. Similarly, the range of minimum to maximum values for PCCP surfaces was 3.5 - 3.9 decibels. This amount of variation produced some overlap in the relative noise levels produced from the two pavement types. Certain PCCP segments produced less tire-pavement noise than some ARACFC segments. For example, the lowest PCCP measurement (94.7 dBA, for grooved PCCP on I-19) was slightly lower than the highest ARACFC noise level (95.3 dBA, on I-10 west of Phoenix). While this inconsistency was observed in some isolated cases, the predominant trend was for the ARACFC surfaces to generate lower on-road noise levels than the PCCP surfaces.

TABLE 5-1 SUMMARY OF ON-ROAD TIRE-PAVEMENT NOISE DATA Grouped by General Pavement Type							
Surface Type	Number of Samples	Mean Leq dBA (10 sec)	Standard Deviation	Min. Value	Max. Value	95 % Confidence Interval for Mean From	To
For 55 MPH							
ARACFC	89	93.4	1.049	91.4	95.3	93.2	93.6
PCCP	97	96.4	1.093	94.7	98.2	96.2	96.7
For 65 MPH							
ARACFC	86	96.1	1.005	93.7	97.6	95.8	96.3
PCCP	83	99.2	1.091	97.1	101.0	99.0	99.4

5.2 Comparison of Individual Freeway Segments

To investigate the wide variation in noise levels observed for two general pavement types, the on-road noise measurements were separated into groups according to the individual freeway segments where the data was collected. Tables 5-2 and 5-3 present the tire-pavement noise measurements grouped by freeway segment. Table 5-2 summarizes the measurement data for travel speeds of 55 miles per hour. Table 5-3 summarizes the noise data for 65 miles per hour. Figure 5-3, provides a graphical summary of the average on-road noise measurements for each segment evaluated for both travel speeds.

The average noise levels presented in Figure 5-3 show the amount of variation in the noise produced by the individual freeway segments. As noted by the standard deviations calculated for each segment (see Tables 5-2 and 5-3), a high degree of consistency was observed in the noise levels measured for individual freeway segments. However, the different freeway segments often produced their own characteristic noise levels.

Figure 5-4 shows average tire-pavement noise levels for each of the individual segments sorted in ascending order. As a group, the ARACFC segments produced lower average noise levels than the various PCCP segments. However, the data indicates that a substantial degree of variability exists among the different ARACFC segments. A similar degree of variability was observed among the various PCCP segments. This variability indicates that the noise generation characteristics of a particular pavement is influenced by factors other than material type alone.

FIGURE 5-1
COMPARISON OF TIRE-PAVEMENT NOISE LEVELS
FOR ALL LOCATIONS AT 55 MILES PER HOUR

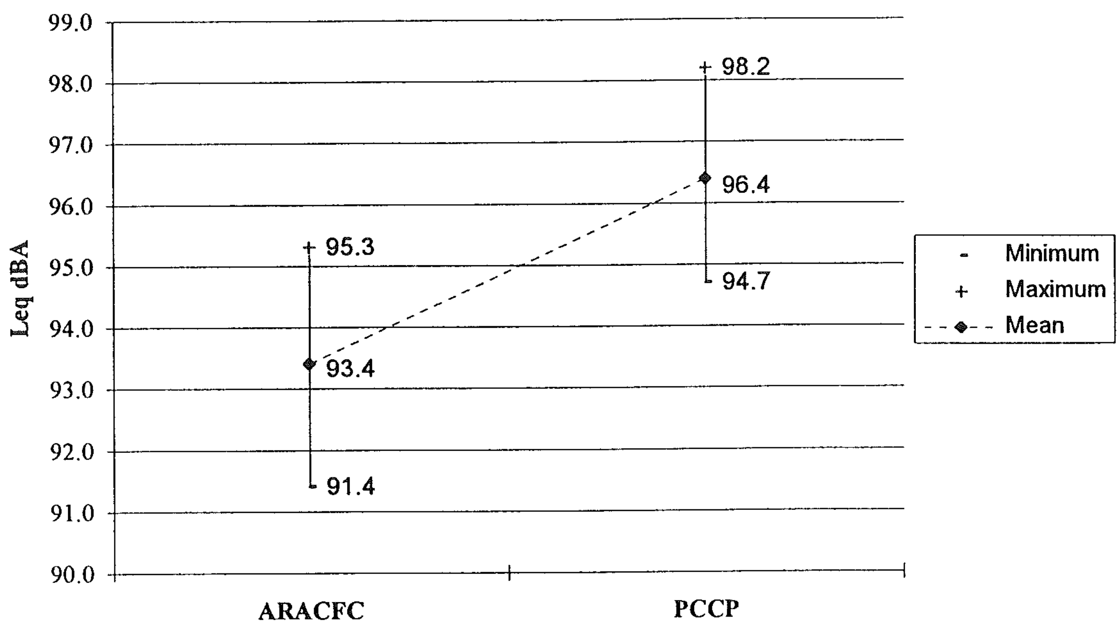


FIGURE 5-2
COMPARISON OF TIRE-PAVEMENT NOISE LEVELS
FOR ALL LOCATIONS AT 65 MILES PER HOUR

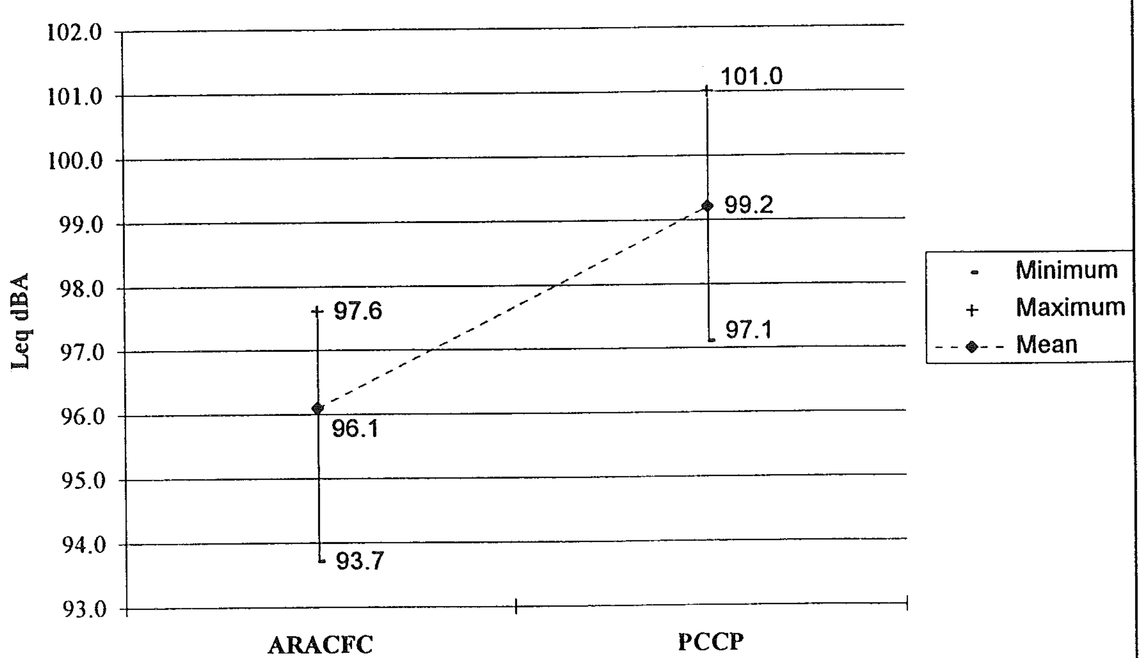


TABLE 5-2
ON-ROAD TIRE-PAVEMENT NOISE MEASUREMENTS AT 55 MILES PER HOUR

Location	Approximate Mile Post	Surface Type	Construction Year	Number of Samples	Standard Deviation	Mean Leq dBA
Location 1: I-10 W. of Phoneix	112.2 - 108.95	ARACFC	1994	34	0.24	94.6
(March 14, 1995)	108.95 - 105.95	PCCP, tined	1994	32	0.35	97.6
	105.95 - 94.72	ARACFC	1994	61	0.44	94.5
Location 2: I-17 Phoenix	226.0 - 214.7	ARACFC	1994	54	0.47	92.7
(March 14, 1995)	199.9 - 198.78	PCCP, ground	1991	7	0.35	96.6
	198.78 - 194.5	ARACFC	1992	27	0.57	94.4
Location 3: I-10 Tucson	267.5 - 261.4	PCCP, ground	1989	66	0.68	96.7
(March 15, 1995)	260.4 - 254.5	PCCP, ground	1983	26	0.54	98.2
Location 4: I-19 Tucson	62.95-60.2	ARACFC	1992	37	0.42	92.3
(March 16, 1995)	60.2-58.48	ARACFC	1988	29	0.81	93.2
	58.48-54.8	PCCP, grooved	1988	46	0.30	95.2
			total samples	419		

TABLE 5-3
ON-ROAD TIRE-PAVEMENT NOISE MEASUREMENTS AT 65 MILES PER HOUR

Location	Approximate Mile Post	Surface Type	Construction Year	Number of Samples	Standard Deviation	Mean Leq dBA
Location 1: I-10 W. of Phoneix	112.2 - 108.95	ARACFC	1994	33	0.31	97.2
(March 14, 1995)	108.95 - 105.95	PCCP, tined	1994	29	0.32	100.4
	105.95 - 94.72	ARACFC	1994	106	0.49	97.0
Location 2: I-17 Phoenix	226.0 - 214.7	ARACFC	1994	23	0.83	95.5
(March 14, 1995)	199.9 - 198.78	PCCP, ground	1991	*not possible due to urban traffic*		
	198.78 - 194.5	ARACFC	1992	6	0.32	95.9
Location 3: I-10 Tucson	267.5 - 261.4	PCCP, ground	1989	39	0.47	99.0
(March 15, 1995)	260.4 - 254.5	PCCP, ground	1983	10	0.30	100.8
Location 4: I-19 Tucson	62.95-60.2	ARACFC	1992	11	0.33	94.7
(March 16, 1995)	60.2-58.48	ARACFC	1988	9	0.54	95.6
	58.48-54.8	PCCP, grooved	1988	15	0.39	97.5
			total samples	281		

FIGURE 5-3
ON-ROAD TIRE-PAVEMENT NOISE DATA (In Leq dBA)
Data Grouped By Location

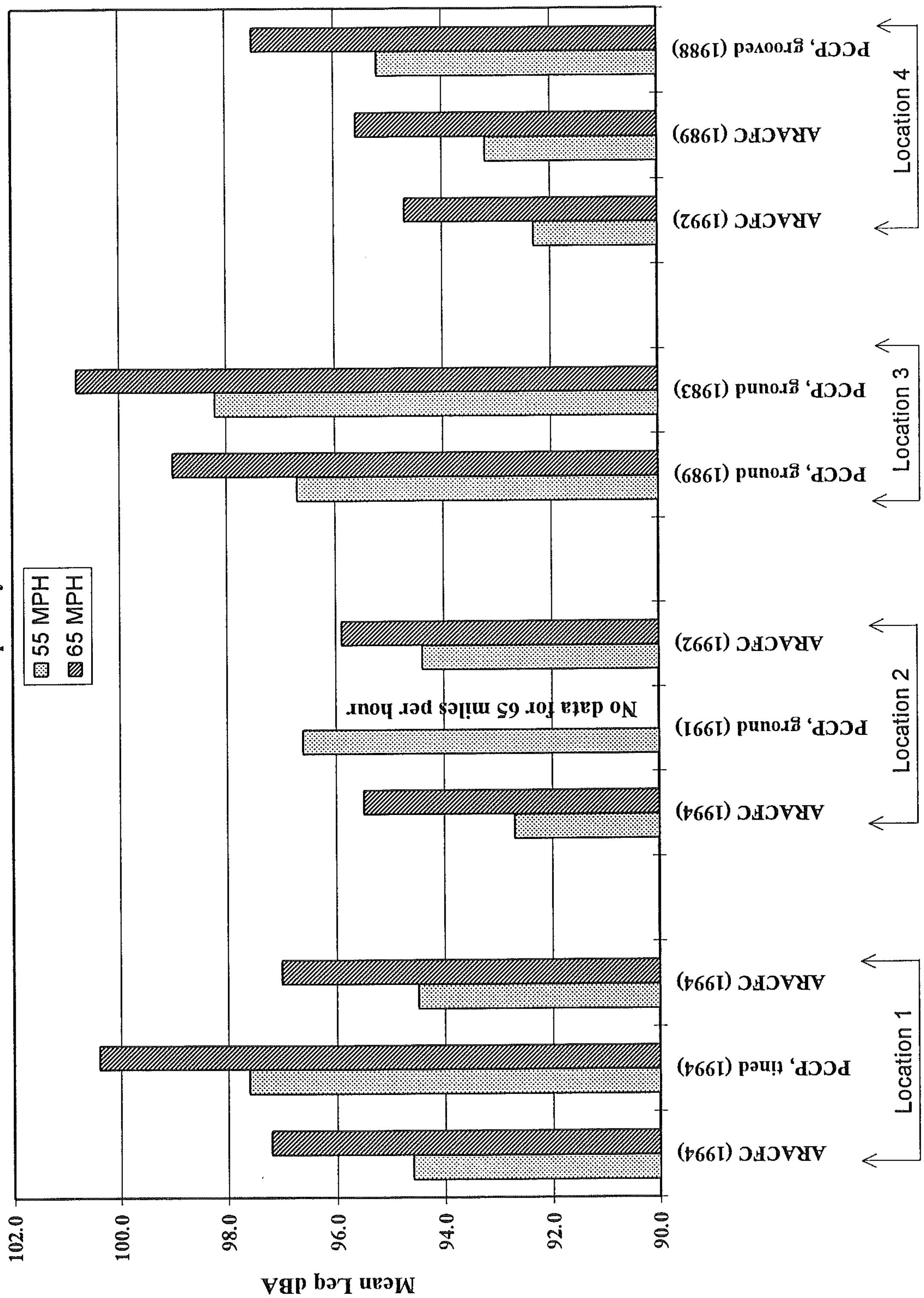
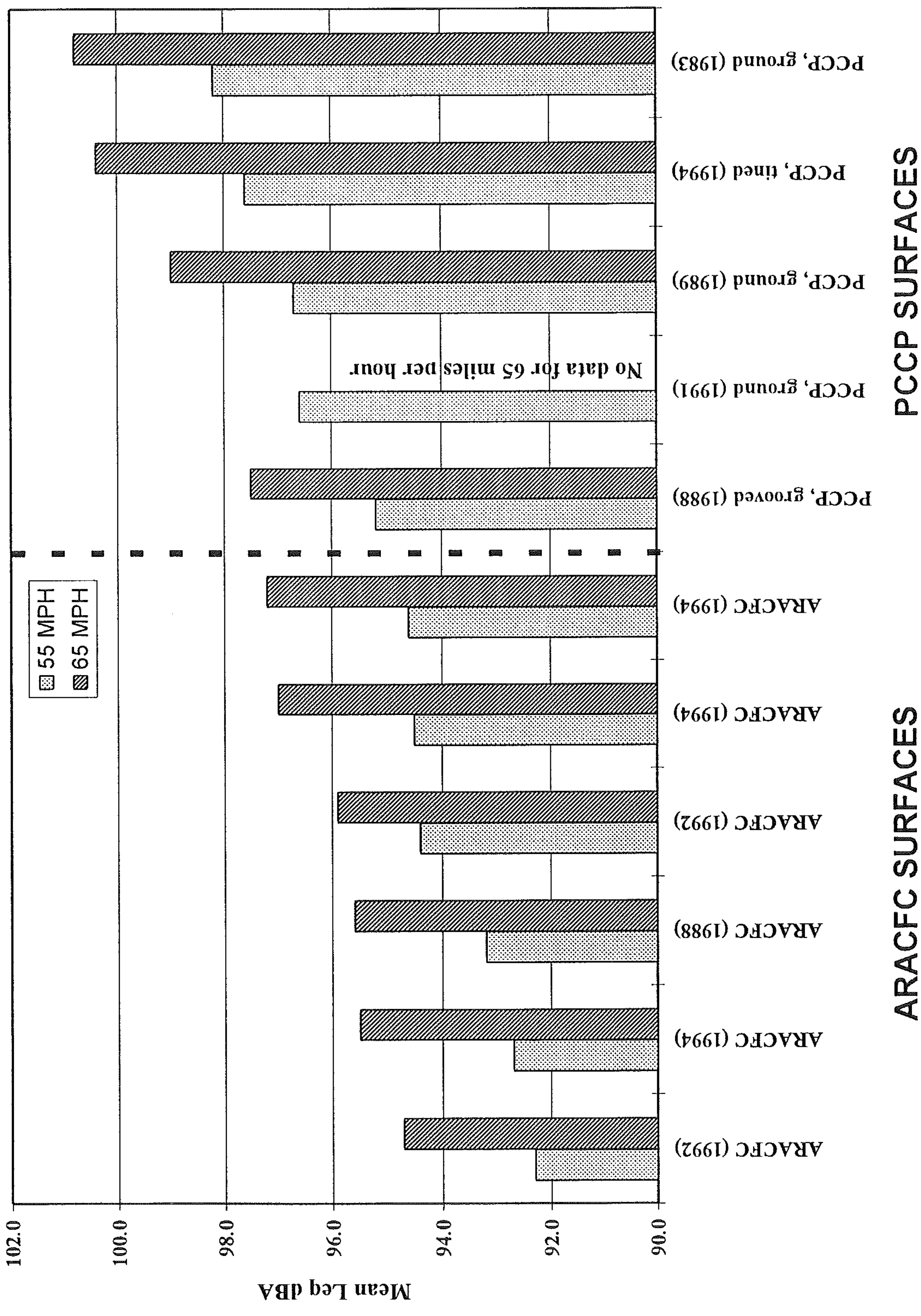


FIGURE 5-4
ON-ROAD TIRE-PAVEMENT NOISE DATA (In Leq dBA)
Data Grouped in Ascending Order by Segment



5.3 Comparison of Pavement Subtypes

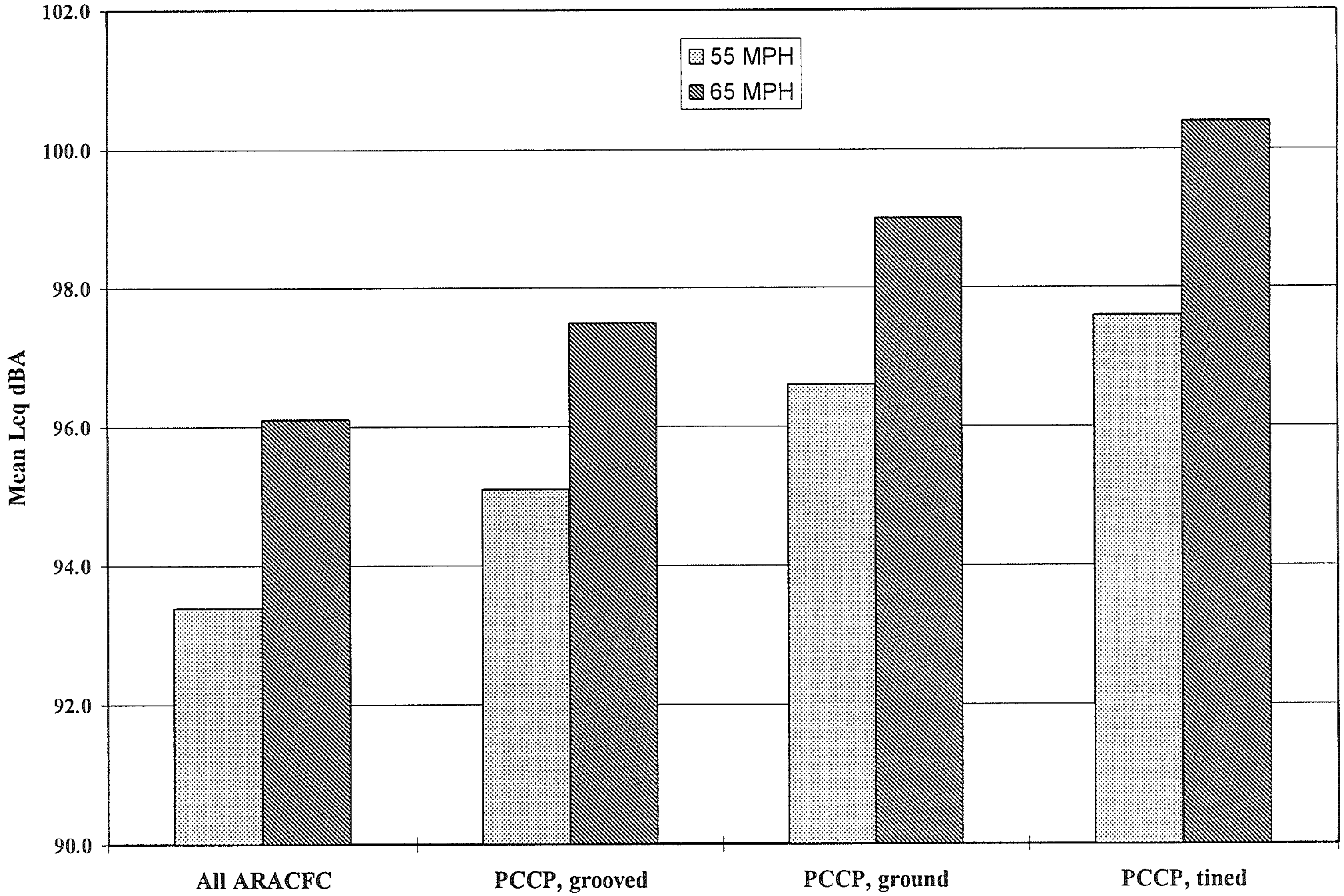
Because of the variation found in the noise produced by pavements constructed with the same material, the on-road noise data was grouped according to pavement subtype. Noise data for the PCCP segments were divided into groups according to surface texture, based on whether the PCCP surface was grooved, ground, or tined. Since no clear means of distinguishing the different ARACFC segments is presently available, noise data for the various ARACFC segments were kept in a single group. Average tire-pavement noise levels by pavement subtype are provided in Table 5-4. This information is presented graphically in Figure 5-5.

As shown in Table 5-4, and Figure 5-5, distinct noise generation characteristics were observed for the different surface subtypes. The group consisting of all ARACFC segments combined resulted in the lowest noise levels. In ascending order, higher noise levels were produced by the grooved PCCP, ground PCCP, and tined PCCP, respectively. Average noise levels for each PCCP subtype differed in noise level by approximately 1.0 - 1.5 dBA from the most similar subtype. Based on this analysis, the three different PCCP surface subtypes have distinctively different noise generation characteristics.

TABLE 5-4
SUMMARY OF ON-ROAD TIRE-PAVEMENT NOISE DATA
Grouped by Pavement Subtype

Surface Type	Number of Samples	Mean LeqdBA (10 sec)	Standard Deviation	Min. Value	Max. Value	95 % Confidence Interval for Mean From	To
For 55 MPH							
ARACFC	89	93.4	1.049	91.4	95.3	93.2	93.6
PCCP,grooved	30	95.1	0.233	94.7	95.6	95.0	95.2
PCCP,ground	37	96.6	0.552	95.8	97.8	96.5	96.8
PCCP,tined	30	97.6	0.363	96.7	98.2	97.5	97.7
For 65 MPH							
ARACFC	86	96.1	1.005	93.7	97.6	95.8	96.3
PCCP,grooved	15	97.5	0.400	97.1	98.2	97.3	97.7
PCCP,ground	39	99.0	0.480	97.9	99.9	98.8	99.1
PCCP,tined	29	100.4	0.324	99.7	101.0	100.2	100.5

FIGURE 5-5
ON-ROAD TIRE-PAVEMENT NOISE DATA (In Leq dBA)
Data Grouped in Ascending Order by Pavement Subtype



Although it was not possible to divide the various ARACFC segments into subtypes, a similar degree of variability was observed in the measurements performed on these segments. It would be useful to investigate the noise properties of the individual ARACFC segments in more detail to determine what factors are responsible for producing the relatively wide range of measured noise levels. An evaluation with this objective in mind would be useful in deriving the maximum noise reduction benefits possible from the ARACFC surface.

5.4 Comparison of Pavements of Different Ages

Data collected using the on-road tire-pavement noise measurement technique was used to evaluate differences in noise levels for pavements of different ages. For this evaluation, noise data for the ARACFC and PCCP sections were evaluated separately. Only PCCP segments of the ground subtype were included in the pavement age analysis. Multiple year data was not collected for the tined or grooved PCCP subtypes.

Results of the pavement age analysis for test speeds of 55 and 65 miles per hour are shown in Table 5-5 and Table 5-6. This information is presented graphically in Figure 5-6 and Figure 5-7, respectively.

No clear trends were observed in the tire-pavement noise data collected on ARACFC surfaces of different ages. Some of the newest ARACFC surfaces tested (the 1994 ARACFC segments found in Location 1) were observed to generate the highest noise levels of all ARACFC surfaces. A different ARACFC freeway segment that was also constructed in 1994 (Location 2), generated the lowest on-road noise levels.

As noted previously in the roadside traffic noise evaluation, little can be said about the aging properties of the various ARACFC surfaces based on the data collected for this study. A high level of variability exists in the noise produced by the different ARACFC segments. However, the differences observed between the various ARACFC segments do not appear to be the result of pavement aging. For this reason, it is suggested that the most appropriate method for evaluating how the noise characteristics of ARACFC surfaces change over time is to periodically measure the noise levels produced by the individual segments as they age.

Data collected for the PCCP segments indicate that a 1983 ground PCCP surface produced significantly higher noise levels than newer (1989 and 1991) ground PCCP surfaces evaluated. There was no difference in average noise levels for the 1989 and 1991 ground PCCP surfaces. However, the 6-8 year age difference between the 1983 PCCP surface and the 1989 and 1991 PCCP surfaces appears sufficient to produce different noise levels.

TABLE 5-5
SUMMARY OF ON-ROAD TIRE-PAVEMENT NOISE DATA FOR ARACFC
Grouped by Pavement Age

Surface Type	Number of Samples	Mean LeqdBA (10 sec)	Standard Deviation	Min. Value	Max. Value	95 % Confidence Interval for Mean From	To
For 55 MPH							
$ARACFC_{1988}$	29	93.2	0.828	92.1	95.1	92.9	93.5
$ARACFC_{1992}$	30	93.4	1.273	91.4	95.3	92.9	93.9
$ARACFC_{1994}$	30	93.6	0.983	91.9	94.9	93.3	94.0
For 65 MPH							
$ARACFC_{1988}$	9	95.6	0.572	94.8	96.2	95.1	96.0
$ARACFC_{1992}$	17	95.1	0.678	94.1	96.6	94.8	95.5
$ARACFC_{1994}$	20	96.5	0.606	95.5	97.6	96.2	96.8

TABLE 5-6
SUMMARY OF ON-ROAD TIRE-PAVEMENT NOISE DATA FOR PCCP
Grouped by Pavement Age

Surface Type	Number of Samples	Mean LeqdBA (10 sec)	Standard Deviation	Min. Value	Max. Value	95 % Confidence Interval for Mean From	To
For 55 MPH							
$PCCP_{1983}$	26	98.2	0.551	97.3	99.9	98.0	98.4
$PCCP_{1989}$	30	96.7	0.590	95.8	97.8	96.4	96.9
$PCCP_{1991}$	7	96.7	0.381	96.0	97.1	96.3	97.0
For 65 MPH							
$PCCP_{1983}$	10	100.8	0.316	100.2	101.2	100.6	101.0
$PCCP_{1989}$	39	99.0	0.480	97.9	99.9	98.8	99.1

One PCCP freeway segment (at Location 3) was used to collect the 1983 PCCP noise data. This segment showed visible signs of wear (cracking) as compared to the other ground PCCP segments evaluated. It should be noted that ADOT has scheduled this freeway segment for pavement rehabilitation in 1995. Planned improvements to this segment include an ARACFC overlay.

FIGURE 5-6

COMPARISON OF AVERAGE NOISE LEVELS FOR FOR ARACFC PAVEMENTS

Data Grouped by Pavement Age

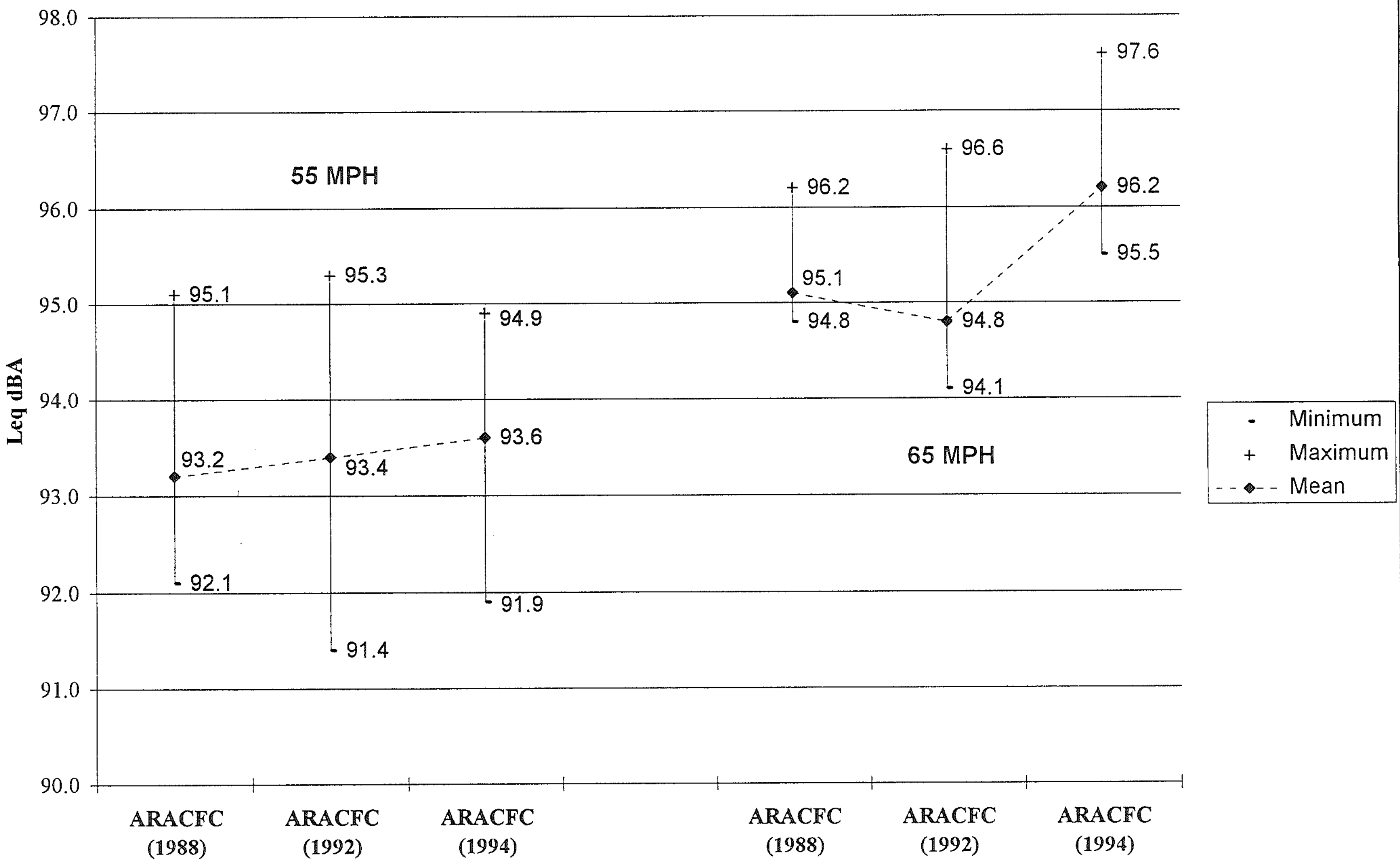
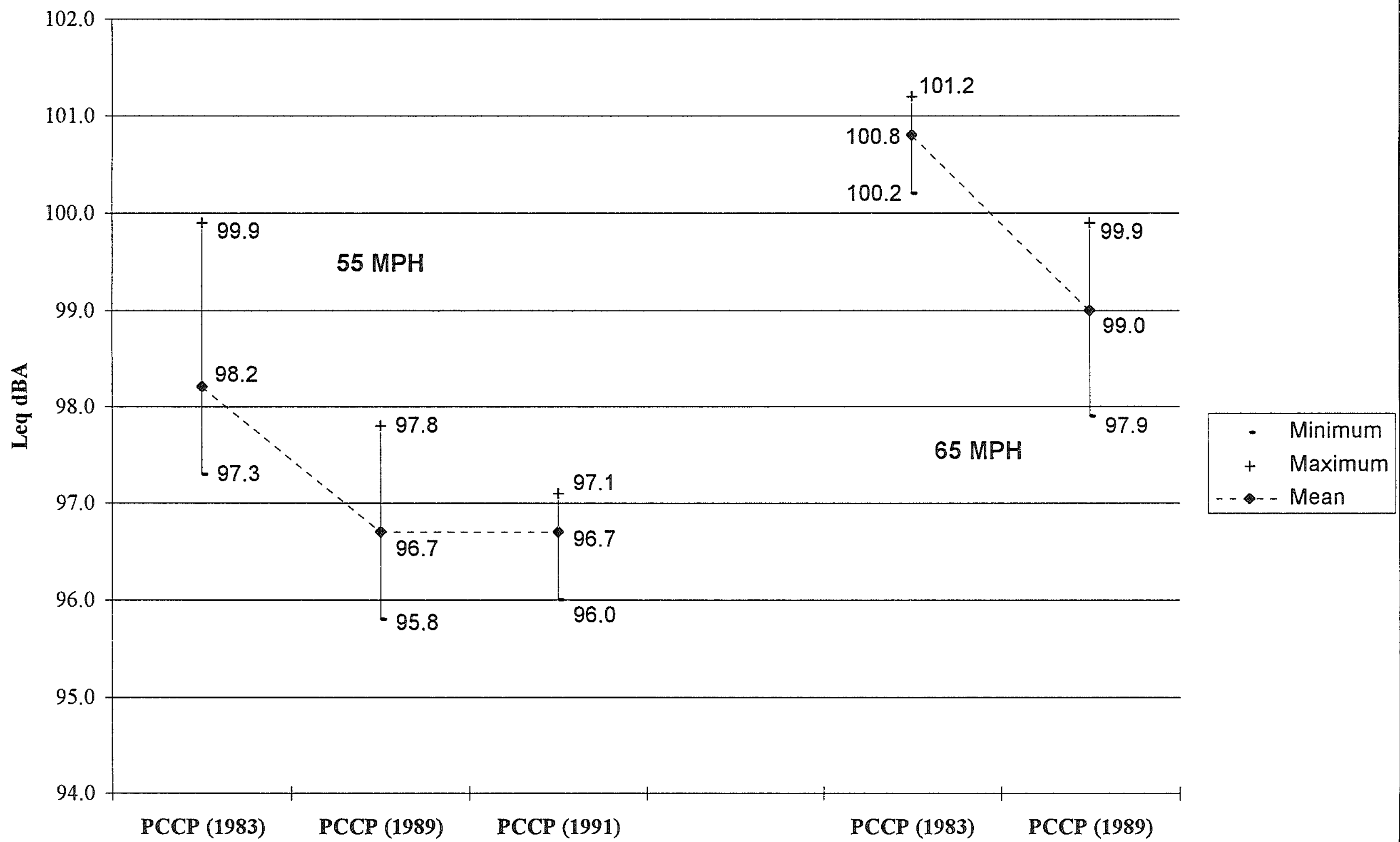


FIGURE 5-7

COMPARISON OF AVERAGE NOISE LEVELS FOR PCC PAVEMENTS

Data Grouped by Pavement Age



6.0 THIRD-OCTAVE FREQUENCY DATA

Both the roadside traffic noise measurements and the on-road tire noise measurements were collected in A-weighted decibels. A-weighting generally corresponds to the human response to loudness across the range of audible frequencies (20 -20,000 Hz). However, more detailed information on the frequency characteristics of the noise generated from the ARACFC and PCCP freeway surfaces was collected. The Rion SA-27 analyzers used for data collection are capable of measuring average noise levels while simultaneously distinguishing the frequency characteristics of the noise being measured. As part of the study, frequency data was collected in third-octave bands using both the on-road and roadside traffic noise measurement techniques. This information was used to provide a comparison of the frequency content of the different freeway surfaces.

As the on-road and roadside noise measurements were being performed, multiple samples of the frequency data were observed in graphical format on the SA-27 analyzers. The frequency patterns produced by the individual freeway segments were observed to be very consistent, therefore only samples were recorded for each roadway segment. Approximately 50 samples of third octave frequency data (averaged over five-minute intervals) were collected as part of the roadside noise measurements. Approximately 40 samples of third octave data (averaged over 10-second intervals) were collected as part of the on-road noise measurements.

A summary of the frequency data that was collected as part of the on-road tire-pavement noise measurements and the roadside traffic noise measurements is provided in the following sections. Complete information of the third-octave frequency data collected is included in Appendix C.

6.1 On-Road Tire-Pavement Noise Measurements

Sample results of the frequency data collected for PCCP and ARACFC surfaces using the on-road measurement technique are presented graphically in Figure 6-1 for PCCP surfaces, and in Figures 6-2 through 6-4 for ARACFC surfaces.

Figure 6-1 shows sample third-octave center frequency data for the three separate types of PCCP roadways. The graphical data consists of three separate 10-second noise measurements as the test vehicle traveled over separate grooved, ground and tined PCCP surfaces at 65 miles per hour. As noted previously, the tined PCCP surface generally produced the highest noise levels, followed by ground and grooved PCCP surfaces. The frequency data for the PCCP surfaces indicates a related pattern of frequency content for the various PCCP surface types even though the overall noise levels differ.

FIGURE 6-1

THIRD-OCTAVE DATA FOR SAMPLE TIRE-PAVEMENT NOISE MEASUREMENTS

PCCP Surfaces at 65 Miles per Hour

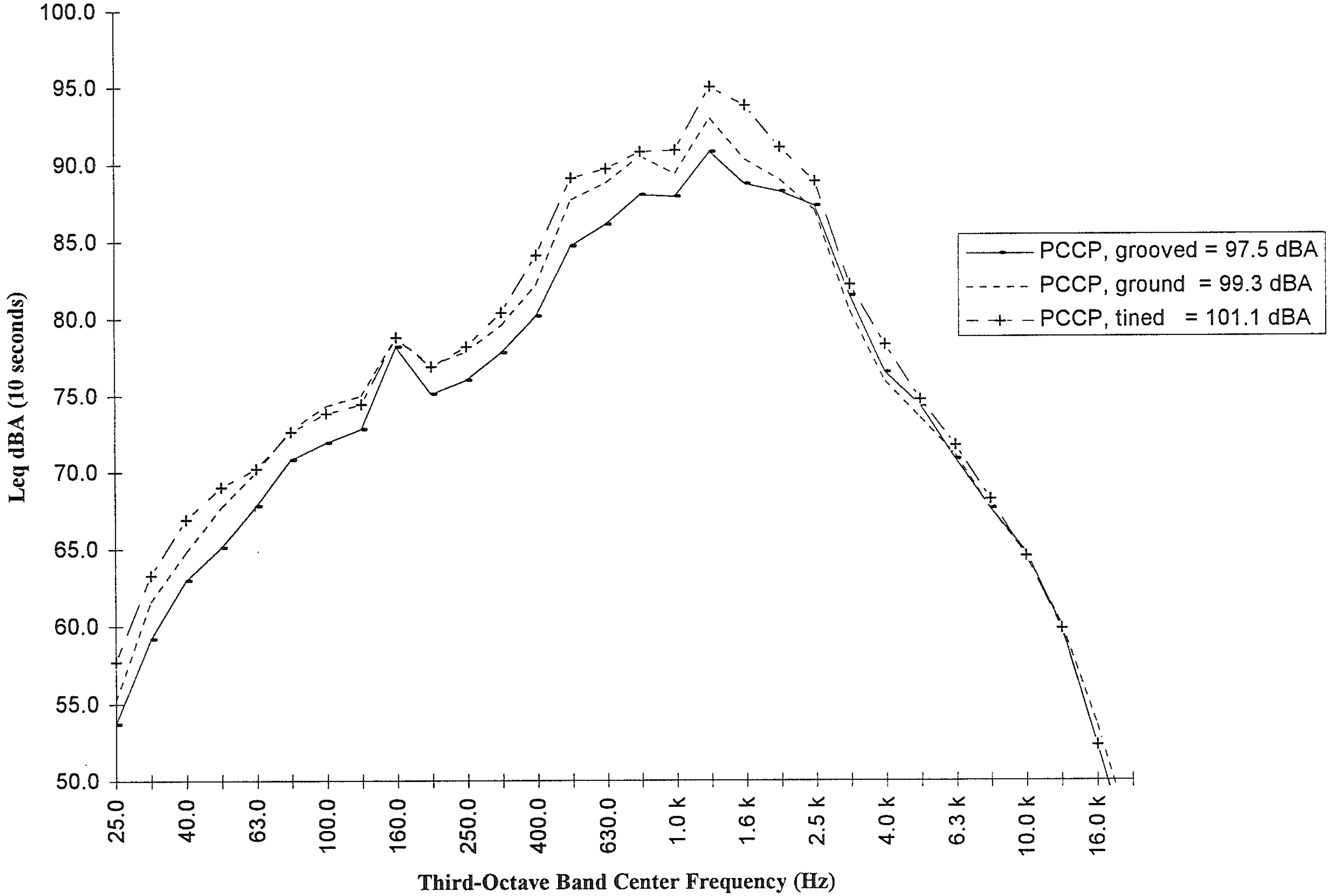


FIGURE 6-2

THIRD-OCTAVE DATA FOR SAMPLE TIRE-PAVEMENT NOISE MEASUREMENTS

ARACFC Surfaces at 55 Miles per Hour

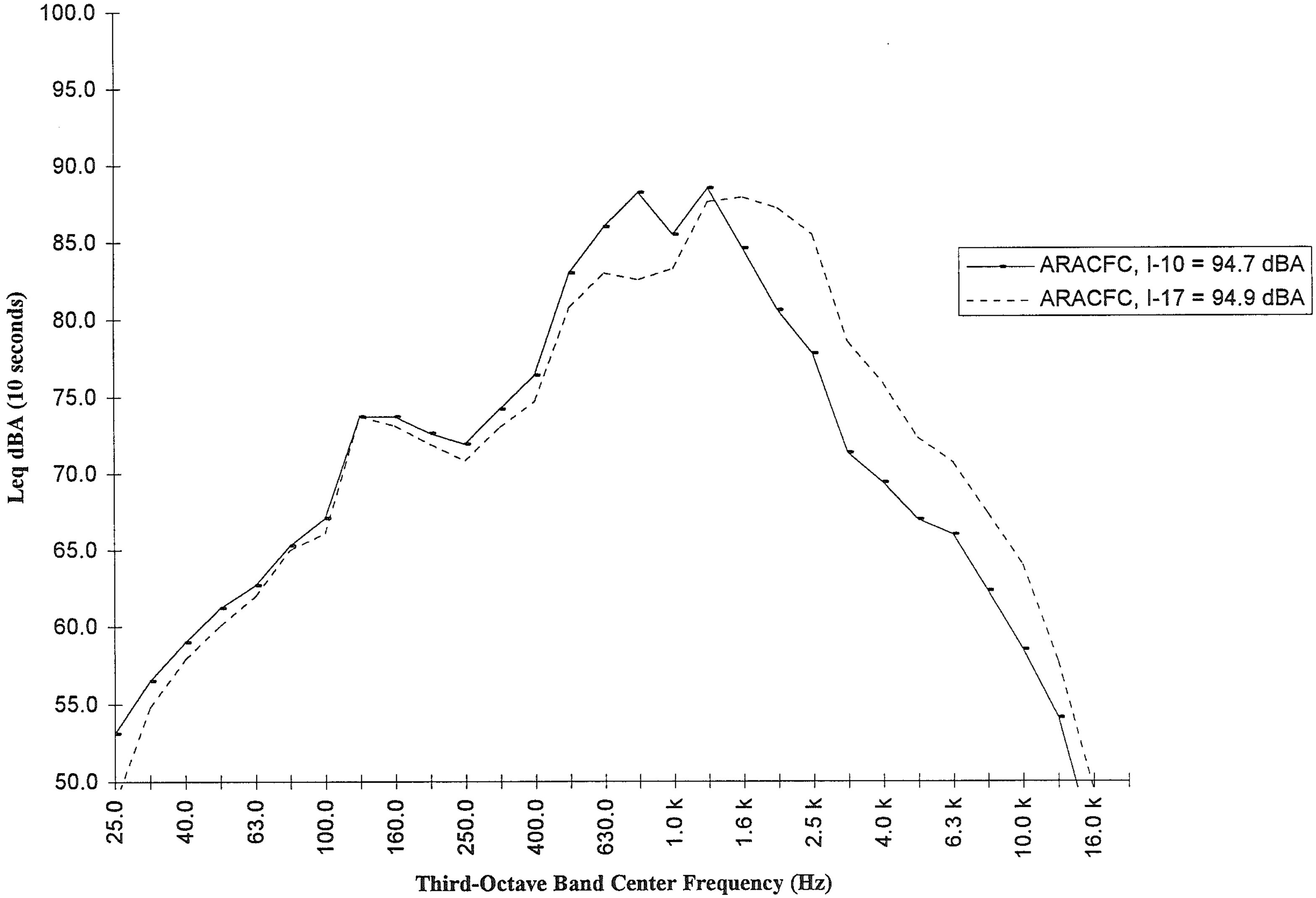
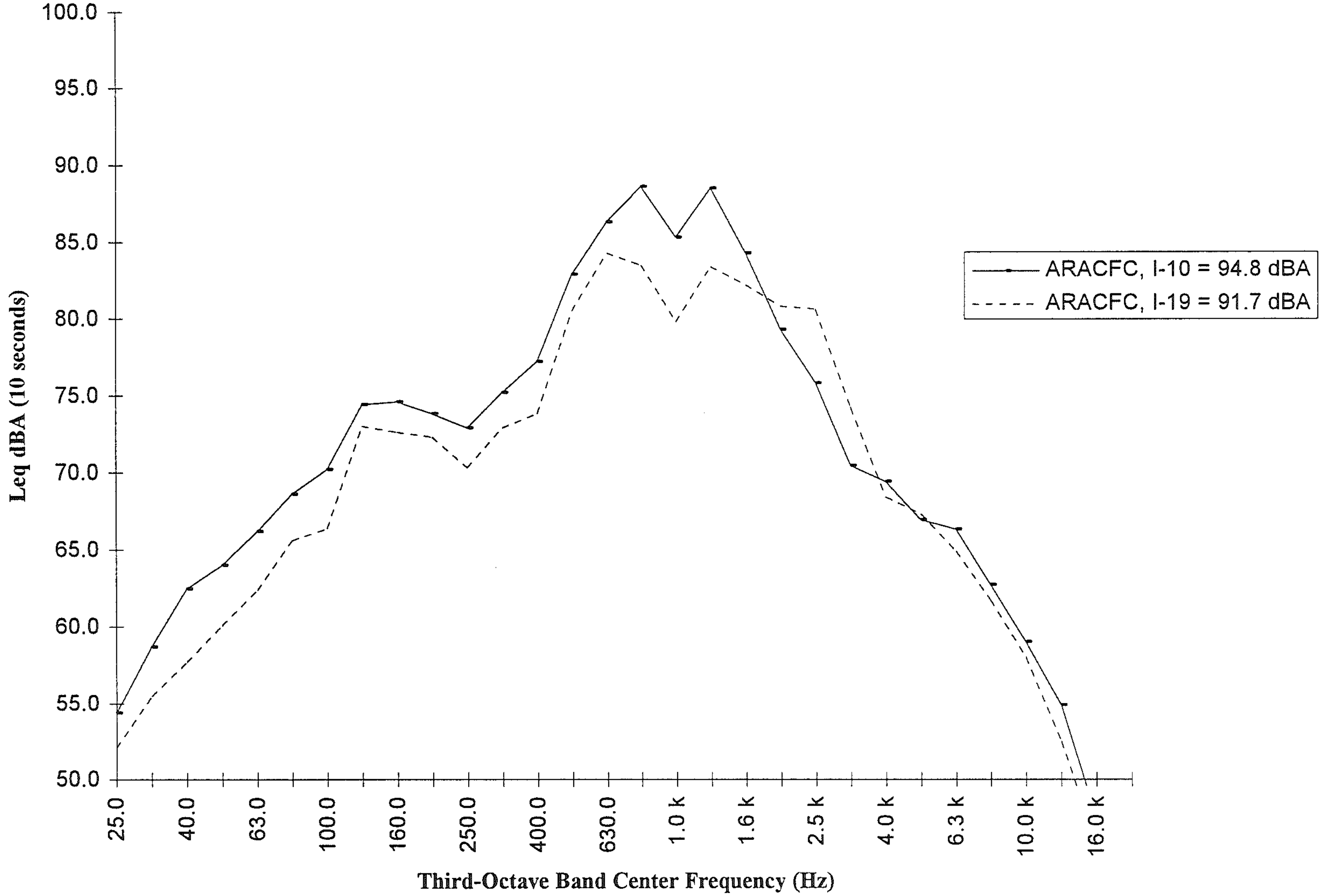


FIGURE 6-3
THIRD-OCTAVE DATA FOR SAMPLE TIRE-PAVEMENT NOISE MEASUREMENTS
ARACFC Surfaces at 55 Miles per Hour

FIGURE 6-4
THIRD-OCTAVE DATA FOR SAMPLE TIRE-PAVEMENT NOISE MEASUREMENTS
ARACFC Surfaces at 55 Miles per Hour



Figures 6-2 through 6-4 show sample comparisons of different ARACFC segments. The frequency data summarized in these figures were collected on various ARACFC segments as the test vehicle traveled at 55 miles per hour. Unlike the PCCP frequency data, distinct differences were observed in the frequency content of the different ARACFC segments. These different frequency patterns support the previous finding that individual ARACFC segments can have distinctively different noise generation characteristics.

6.2 Roadside Traffic Noise Measurements

Third-octave frequency data for selected roadside measurements are provided in Figures 6-5 through 6-7. These figures summarize the frequency data collected at the same sites where simultaneous roadside noise measurements were performed. Data was selected in this manner in order to minimize the effects that differences in traffic (traffic volume, truck percentages, and vehicle speeds) might produce in the frequency data being compared. The differences in the roadside noise frequency patterns shown in Figures 6-5 through 6-7 are attributed to the different character of the noise produced by the different freeway segments. In each figure, sample on-road tire-pavement frequency data for the same locations is also provided for comparison.

Figure 6-5 shows sample third-octave band frequency data for roadside and on-road noise measurements conducted at Location 1. As shown in Figure 6-5, the frequency content of the roadside noise for ARACFC and tined PCCP surfaces is most different in the 800 - 3150 Hz frequency regions. In general, human perception is most sensitive to noise frequencies in the range of 1000 - 4000 Hz. Noise in these frequency regions are also generally regarded as more annoying, especially when discrete frequency components (pure tones) are present. For this study, it was not possible to assess how the frequency content of these two surfaces might be subjectively interpreted in terms of annoyance. However, based on the preliminary investigation, it is clear that two different surfaces produce noise that differ in character. The tined PCCP surface would not only be perceived as producing a slightly higher noise level, but it would also be perceived as producing noise with a higher frequency content.

Figure 6-6 compares the frequency content of roadside noise produced from grooved PCCP and 1988 ARACFC. Figure 6-7 compares the frequency content of noise from the two ARACFC pavements of different ages. As shown in the figures, these different pavement surfaces produce roadside noise with distinctly different frequency patterns, even though differences in their overall noise levels were minor.

FIGURE 6-5

THIRD-OCTAVE DATA FOR SAMPLE ON-ROAD AND ROADSIDE NOISE MEASUREMENTS

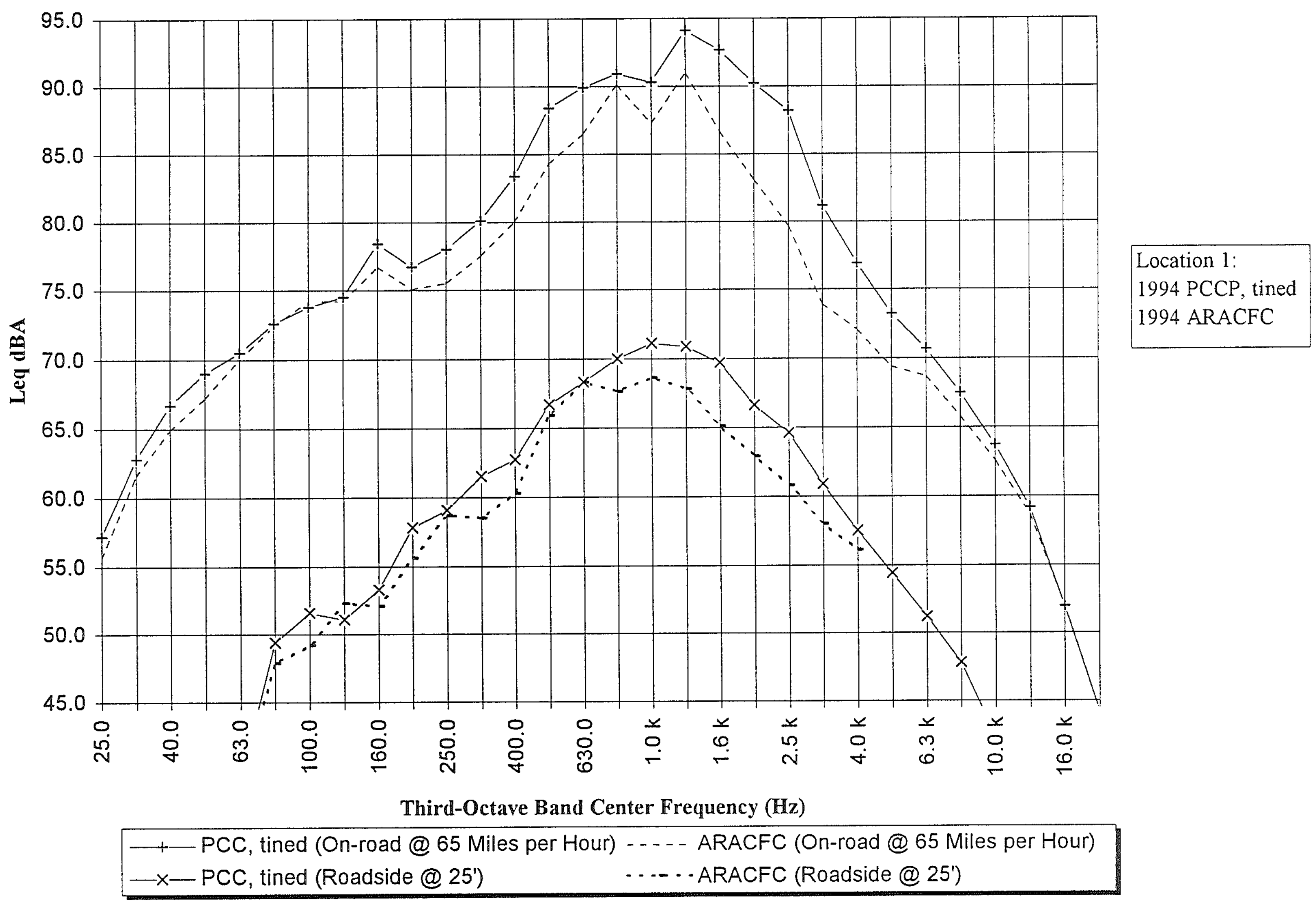


FIGURE 6-6

THIRD-OCTAVE DATA FOR SAMPLE ON-ROAD AND ROADSIDE NOISE MEASUREMENTS

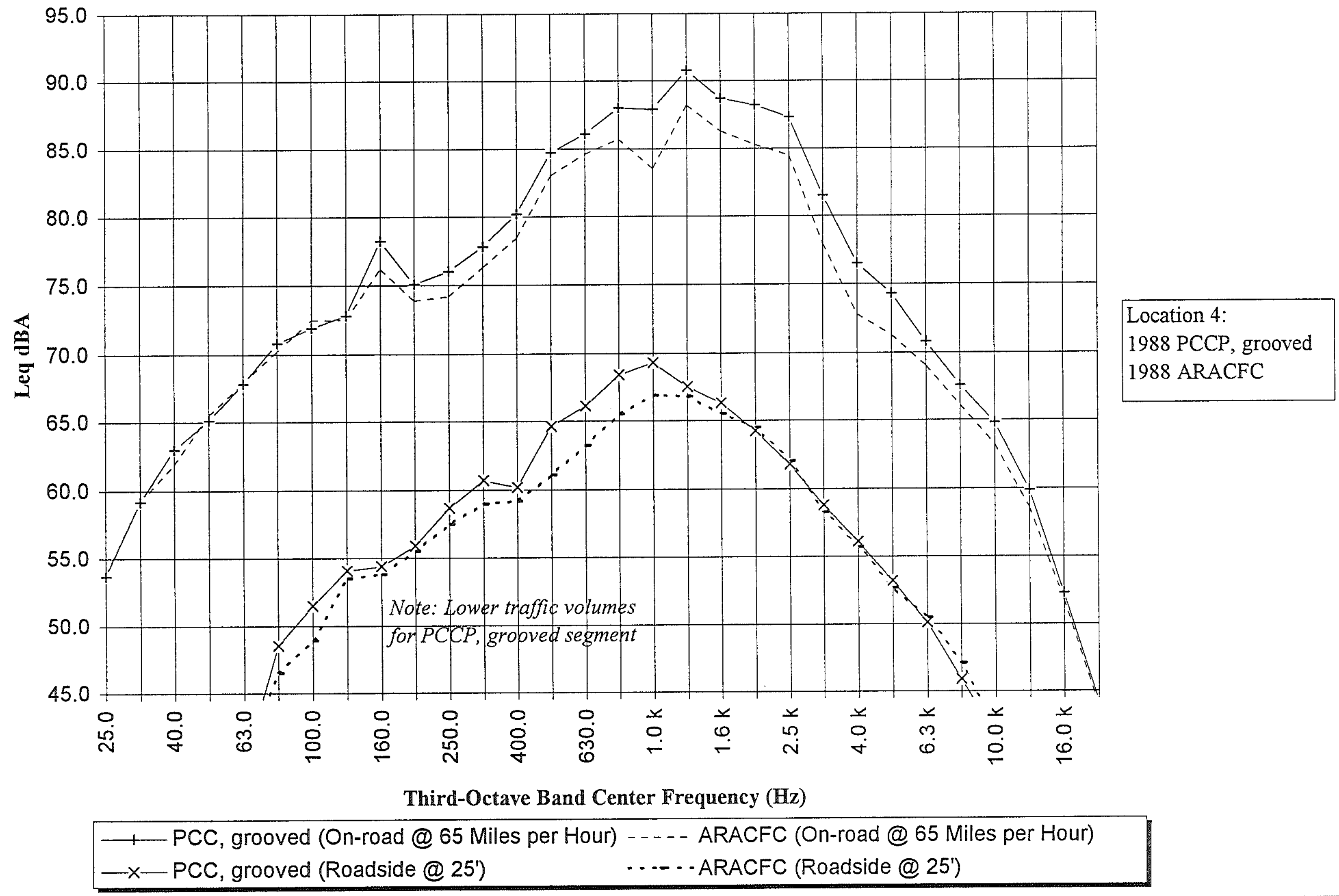
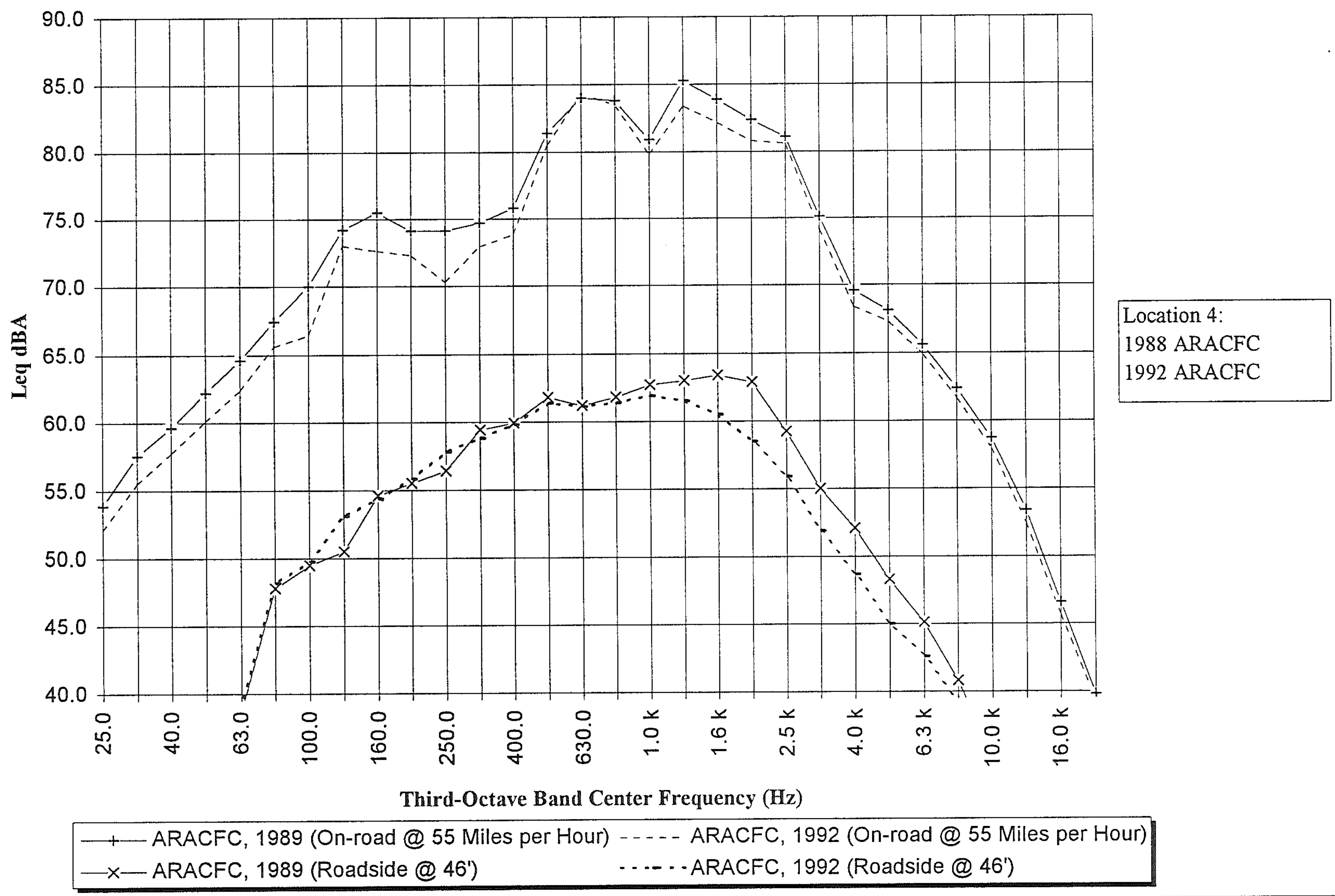


FIGURE 6-7

THIRD-OCTAVE DATA FOR SAMPLE ON-ROAD AND ROADSIDE NOISE MEASUREMENTS



Also shown in Figures 6-5 though 6-7 are sample third-octave frequency components for on-road tire-pavement noise readings for the same freeway segments. The gross patterns between the frequency content of the roadside and on-road noise measurements are similar. However, less distinct peaking characteristics are found for the roadside measurements, which results in a smoother frequency pattern.

Differences observed in the frequency patterns between the on-road and roadside noise measurement methods are attributed to the different measurement techniques. The on-road noise measurements should be viewed as an attempt to isolate noise produced from the tire-pavement interaction from a single test vehicle (with a single tire type and tread pattern). The roadside traffic noise measurements consider tire-pavement noise as well, however, tire-pavement noise that is transmitted to the roadside environment is comprised of noise generated from the wide variety of vehicles and tire types present in the vehicle stream. Furthermore, the roadside traffic noise measurements represent a variety of additional factors, such as vehicle engine and exhaust noise (especially from heavy trucks), site acoustics, as well as noise produced from background sources. The roadside frequency data reflects this diverse combination of factors which act in combination to smooth the more defined peaks associated with the on-road measurements of the test vehicle.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Two different measurement techniques were used to compare the noise generation characteristics of Asphalt Rubber Asphalt Concrete Friction Courses (ARACFC) and Portland Cement Concrete Pavements (PCCP). Roadside traffic noise measurements and on-road tire-pavement noise measurements were conducted at selected freeway locations to compare the relative noise levels produced by the two pavement types. The noise data collected using both measurement techniques demonstrate that ARACFC freeway surfaces produce lower noise levels than PCCP surfaces. It is not clear whether the noise reduction benefits are the result of asphalt-rubber materials used in the ARACFC. Based on the findings of several previous studies, differences in pavement surface texture are likely to be a critical factor in the relative noise levels produced by the PCCP and ARACFC segments evaluated in this study. A summary of the noise data collected using roadside traffic noise measurements and on-road tire-pavement noise measurements is provided below.

7.1 Simultaneous Roadside Traffic Noise Measurements

Simultaneous roadside traffic noise measurements were conducted adjacent to adjoining freeway segments with different pavement surfaces. In every case, roadside noise levels were higher for PCCP pavements than for ARACFC pavements. A range of differences was observed in the hourly equivalent noise levels measured at each pair of roadside measurement sites. The differences observed in the roadside noise levels are summarized below.

- Roadside noise levels near a tined PCCP surface were 3.3 - 5.7 dBA greater than levels measured near an adjoining ARACFC surface. Based on four separate hourly measurements, the average difference between the two surfaces was 4.7 dBA.

- Roadside noise levels near an ARACFC surface that was constructed in 1988 were 0.6 - 1.5 dBA greater than levels measured near an adjoining ARACFC surface that was constructed in 1992. Based on four separate hourly measurements, the average difference between the two surfaces was 1.0 dBA.

- Roadside noise levels near a grooved PCCP surface were 0.2 - 2.1 dBA greater than levels measured near an adjoining ARACFC surface. Based on four separate hourly measurements, the average difference between the two surfaces was 1.4 dBA.

7.2 On-Road Tire-Pavement Noise Measurements

A specially made bracket was used to attach a noise meter microphone on the exterior of a test vehicle. The microphone was secured near the tire-pavement contact area and noise levels were measured as the test vehicle was driven over different pavement surfaces. Average noise levels for the various pavement surfaces were compared to give an indication of their relative noise generation characteristics. Results of the on-road tire-pavement noise measurements are summarized below.

- On-road tire-pavement noise levels for PCCP surfaces were approximately 3 dBA greater than noise levels measured for ARACFC surfaces. The average difference of 3 dBA was consistent for travel speeds of both 55 and 65 miles per hour.

- A relatively wide range of noise levels was observed for both PCCP and ARACFC surfaces. However, individual pavement segments tended to produce consistent noise levels.

- Because of the variability found in the on-road noise measurements, noise data from the PCCP surfaces were grouped according to whether their surfaces were tined, ground, or grooved. This analysis indicated that the three PCCP subtypes produced distinctly different noise levels.

- There was no clear means of grouping the noise levels associated with the different ARACFC freeway segments. However, a similar degree of variability was found on the different ARACFC segments as was found on the PCCP segments.

- No relationships were found regarding the different noise levels produced by ARACFC segments of different ages. Other factors appear to be responsible for the variation found in noise levels for the different ARACFC surfaces.

- Due to the high variability found for the different ARACFC surfaces, it is recommended that the most appropriate method for evaluating how the noise characteristics of these surfaces change over time is to periodically evaluate the individual surfaces as they age.

- It is recommended that the various ARACFC segments be investigated in greater detail to determine what factors are responsible for producing the relatively wide range of noise levels observed for this surface type. This information would be useful in deriving the maximum noise reduction benefits possible from the ARACFC surface.

- Statistically significant noise level differences were observed when comparing a 1983 ground PCCP surface with 1989 and 1991 ground PCCP surfaces. Average on-road noise levels were 1.5 - 1.8 dBA higher for the older PCCP surface.

7.3 Third-Octave Frequency Data

Sample third-octave frequency data was collected for both the roadside traffic and on-road tire-pavement noise measurements. Results of the frequency evaluation of the various pavement surfaces is summarized below.

- Individual freeway segments tended to produce consistent frequency patterns for both the on-road and roadside noise measurements.

- Third-octave band frequency patterns were very similar for the various PCCP segments evaluated, regardless of whether the surface was tined, grooved or ground. Variation was observed in the frequency patterns produced by the different ARACFC segments.

- Roadside measurements for a tined PCCP surface produced higher noise levels than an adjoining ARACFC surface in the 800 - 3150 frequency regions, the frequency region where human perception is most sensitive.

- For the roadside noise measurements, distinct differences were observed in the frequency patterns of different the freeway surfaces being compared. This finding indicates that the different surfaces produce a different character of noise in terms of frequency as well as overall noise level.

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